SUDBURY ENVIRONMENTAL STUDY

AN ANALYSIS OF THE IMPACT OF SMELTER EMISSIONS ON PRECIPITATION QUALITY AND WET DEPOSITION IN THE SUDBURY AREA: SUDBURY ENVIRONMENTAL STUDY EVENT PRECIPITATION NETWORK RESULTS.

SES 006/82

FALL 1982

Ministry of the Environment
Ontario

The Honourable
Keith C. Norton, Q.C.,
Minister

Gérard J. M. Raymond
Deputy Minister

SUDBURY ENVIRONMENTAL STUDY

AN ANALYSIS OF THE IMPACT OF SMELTER EMISSIONS ON PRECIPITATION QUALITY AND WET DEPOSITION IN THE SUDURY AREA: SUDBURY ENVIRONMENTAL STUDY EVENT PRECIPITATION NETWORK RESULTS.

SES 006/82

by

Walter H. Chan, Al J.S. Tang and Maris A. Lusis
Special Studies Unit
Atmospheric Research and Special Programs Section
Air Resources Branch
Ontario Ministry of the Environment
880 Bay Street, 4th Floor
Toronto, Ontario, Canada, M5S 1Z8

and

Robert J. Vet
Concord Scientific Corporation
2 Tippett Road
Downsview, Ontario, Canada, M3H 2V2

and

Chul-Un Ro
Petro-Canada, Engineering/Drilling Division
P.O. Box 2844
Calgary, Alberta, Canada, T2P 2M7

October 1982

S.E.S. Coordination Office
Ontario Ministry of Environment
6th Floor, 40 St. Clair Ave. W.
Toronto, Ontario, Canada, M4V 1M2
Project Coordinator: E. Piché

SES 006/82
ISBN 0-7743-7101-3
ARB-05-82-ARSP

SYNOPSIS

This report extends an earlier analysis of the impact of the Sudbury smelter emissions on the Sudbury area[1] to a larger set of event precipitation data. Included are approximately 180 rain and snow events during the period mid-1978 to mid-1980, with precipitation samples collected upwind and downwind of both the INCO and Falconbridge Nickel Smelters in Sudbury, Ontario[2]. Of primary interest were two questions[3]:

(1) What is the fate of the smelter emissions during precipitation events i.e., how efficiently are they, on average, removed from the atmosphere, and how far from the source can the smelter effect be detected during storms in the Sudbury area?

(2) What is the impact of the smelter sources on the local precipitation quality and deposition pattern?

The results of the present analysis were in basic agreement with the earlier work[1] (of course, the use of a larger data base modified some of the earlier numerical values of concentration, deposition and smelter impact), and may be summarized as follows:

---

1. Ministry of the Environment Report No. ARB-TDA-35-80, "An Analysis of the Impact of INCO Emissions on Precipitation Quality in the Sudbury Area", May, 1980.
2. A companion report, ARB-04-82-ARSP, "Precipitation Quality and Wet Deposition in the Sudbury Basin: Sudbury Environmental Study Cumulative Precipitation Network Results", considers the effect of the smelters on the long-term wet deposition in the Sudbury area.
3. Note that the report also includes other analyses of the data, such as statistical summaries of the observations (Table 4), correlation analysis, estimates of sulfur dioxide conversion rates in the INCO plume under "wet" conditions, and comparisons of rain and snow scavenging rates for the various emitted substances.

(1) With the exception of copper and nickel, most of the wet deposition in the Sudbury area (within a radius of 40 Km) can be attributed to sources other than the local smelters[4]. Long-range transport from sources to the south is implicated for many parameters, notably acidity and the acid-precursors, sulfate and nitrate, because significantly higher background precipitation concentrations occur in warm, than in cold, frontal storms. The former usually enter the study area from south of Sudbury.

(2) Nevertheless, a definite influence of the smelters on the local downwind precipitation quality can be detected for almost all the substances known to be emitted, the contribution due to INCO being considerably larger than that due to Falconbridge (in qualitative agreement with their respective emission rates). For example, average downwind precipitation copper and nickel concentrations were found to be an order of magnitude higher than background values in INCO's case[5]. In many cases, the INCO smelter influence can be detected at distances of more than 40 Km from the source.

(3) Most particulate constituents (acids, sulfates, trace metals) are scavenged quite efficiently, typically more than 30%, from the smelter plumes during both rain - and - snow - storms, with almost total removal occurring within the Sudbury area (r = 40 km) for some trace metals (e.g. copper)[4]. The percentage of total emitted sulfur scavenged by precipitation locally is much lower, mainly because this

---

4. Refer to tables 22 and 23 of the report for details.
5. See tables 13 and 14 in the report, which compare the mean plume sector and background precipitation concentrations for INCO and Falconbridge.

sulfur is largely in the form of sulfur dioxide, which is subject to a low precipitation scavenging efficiency.

(4) During precipitation events, the INCO smelter contributes, on average, 70% of the total copper and nickel wet deposition within 40 Km, and less than 20% of the total for other trace metals and sulfur.

(5) Table S1 summarizes the results, for wet depositon during precipitation events for some of the substances emitted by the INCO smelter. Although similar information is derived for Falconbridge in the report, it is thought to be considerably less accurate, (due to much poorer network coverage around the Falconbridge smelter, and possible interferences from the larger INCO smelter's emissions), and will not be presented here.

In connection with the above results, two facts should be pointed out. Firstly, the smelter contribution to total on deposition, indicated in column 5 of Table S1, applies only to the level of smelter emissions (column 2) that occured during the study period. Any change in emission rates is expected to cause a corresponding change in the smelter contribution. Secondly, the percentage of smelter emissions removed (column 4) is computed only for periods when precipitation was actually occurring. These constitute about 10% of the total time; various dry deposition and transport processes providing the only removal pathway during the remainder. The effect of the smelters on dry deposition in the Sudbury basin is discussed in Report ARB-012-81-ARSP, "An Analysis of the Impact of Smelter Emissions on Atmospheric Dry Deposition in the Sudbury Area: Sudbury Environmental Study Airborne Particulate Matter Network Results".

TABLE S1: AVERAGE WET DEPOSITON OF INCO EMISSIONS WITHIN A 40 KM RADIUS OF THE SMELTER DURING A PRECIPITATION EVENT

	Emitted (Kg)	Deposited (Kg)	% Emissions Removed	% INCO Contribution to Total Wet Deposition+
H_f*	4.5×10^2	1.4×10^2	32	6
SO_4	2.2×10^4	1.0×10^4	48	8
Total-S	5.2×10^5	3.4×10^3	0.7	8
Fe	7.1×10^2	4.8×10^2	68	20
Cu	2.6×10^2	2.7×10^2	100	69
Ni	3.5×10^2	1.3×10^2	36	67
Pb	2.1×10^2	0.7×10^2	33	14
Zn	0.55×10^2	0.5×10^2	93	12
Al	3.9×10^2	1.8×10^2	80	8
Cd	0.16×10^2	0.04×10^2	23	28
Cr	0.52×10^2	0.01×10^2	2.3	8

* Free hydrogen

\+ (INCO Deposition)/(INCO Deposition + Background Deposition) x 100%

TABLE OF CONTENTS

TABLE OF CONTENTS

Page

CONTENTS OF SUPPLEMENTARY VOLUME

LIST OF TABLES

LIST OF TABLES

Number | Page

LIST OF FIGURES

ACKNOWLEDGEMENTS

The authors would like to thank the following key personnel for making this work possible: Mr. K.D. Hawley, now with the Northeastern Region and Mr. S. Linauskas, now with Atomic Energy Canada Limited, who were both involved in the field coordination of the network, Messrs. W. Bardswick, M. Dutka, S. Elliot, and R. Wright as well as Ms. M. Brideau, N. Keller and C. Mentrycki all of whom participated directly in the sampling program; Mr. R. Chiu who was in charge of the data base management and Mr. C. Hui for compiling the statistics; Messrs J. Kurtz and F. De Rango for the air parcel trajectory analysis.

Thanks are also due to our colleagues in the MOE - Laboratory Services Branch for their analytical support. Among these people, special thanks are due to Mr. F. Tomassini and Dr. B. Loescher for coordinating the laboratory efforts. Critical review and comments of the report by Drs. D. Balsillie, L. Barrie, P. K. Misra and Mr. L. Fitz are gratefully acknowledged.

1. INTRODUCTION

As part of the overall effort of the Sudbury Environmental Study (SES) in understanding the fate of pollutants emitted from the local sources in Sudbury, the Air Resources Branch operated two precipitation sampling networks to study wet deposition in the area. One network - the cumulative network - was designed to measure the long term wet deposition pattern in the greater Sudbury area. The other network - the event network - was designed to identify the relative contributions of the smelter emissions and "background" material to the local precipitation quality.

The event network was in operation for two years from June, 1978 to May, 1980. During part of 1978 and 1979, the two major local sources of pollutant emissions, the INCO and Falconbridge nickel smelters, were not operating, either due to scheduled shutdowns or labor disputes. Results pertaining to the long term loading pattern of the various pollutants, i.e. from the cumulative network, are described in another report(1). This present report is focussed on the two years data obtained from the event network only and is a sequel to two other reports (2, 3) published previously, based on partial data set.

Because of the unavailability of suitable sites for precipitation sampling, the network primarily yielded useful information on INCO. Network coverage in the vicinity of the Falconbridge smelter was relatively poor and the results discussed in this report on that source should be regarded with considerable caution.

The tables in this report summarize only the most relevant results. Readers interested in more details are referred to the Supplementary Volume, which is available on request from the Air Resources Branch. Contents of this Volume are given at the end of the Table of Contents of the present report.

2. THE NETWORK

The SES Event Precipitation Monitoring Network began operation in June 1978 and continued until May 1980. It was operated concurrently with, but independently of, the SES Cumulative Precipitation Monitoring Network. This latter network and the history of the Air Resources Branch participation in precipitation monitoring in the Sudbury area are described in detail in another document (1). It is mentioned here only to indicate that the Air Resources Branch has been involved in several areas of precipitation monitoring.

2.1 Objective

The objective of the SES Event Network was to quantify the relative contribution of the local smelter emissions from INCO and Falconbridge to precipitation quality and wet deposition in the Sudbury area.

2.2. Network Design and Operation

In order to fulfill the above objective, a precipitation network was operated from mid-1978 to mid-1980 within primarily a radius of 50 Km from Sudbury. The number of sites varied from summer to winter, typically 25 in the summer and less than 15 in the winter. Stringent siting criteria were followed in the sampler placement. Due to constraints of suitable sites and operators, the final network was designed primarily to assess the impact of the INCO source on the local environment. It should be noted that some sampling sites were also in the vicinity of the

Falconbridge source and could be used to estimate its contribution to wet deposition. Figure 1 is a map of all of the sites used (except for the distant locations - Charlton Station, Ramsay, Thessalon and Blind River) during the two-year period and the site locations are defined in Table 1. These stations were operated for different lengths of time and these are summarized in Table 2.

Two designs of sampler/bag inserts (see Appendix 1) were used in the daily sampling which typically operated from 0800-0800 hours. These consisted of large diameter open polyethylene collectors with a collection area of 1,410 cm^2.

Collected samples were analyzed for acids, major ions and trace metals using conventional techniques, e.g. Dionex ion chromatography and atomic absorption spectroscopy. An outline of the methods used is given in Table 3. Efficiency of collection for rain was quite high, over 80% on the average, whereas that for snow was lower and quite variable. The number of samples collected at each station with volume and pH measurements made is given in Table 2.

Detailed descriptions of the network design, instrumentation, sampling procedures, chemical analysis and network performance can be found in Appendix 1.

3. SES PRECIPITATION NETWORK RESULTS

3.1 Data Presentation

Data obtained at all the sites over the lifetime of the network are tabulated in Section 1 of the Supplementary Volume according to sampling station and sampling date. Sampling time usually was from 0800-0800 hours ($\pm$2 hour). Precipitation time was recorded whenever it was feasible. The type of precipitation is designated as 1,2, or 12 to represent rain, snow or mixed rain and snow respectively. Taking into account the size of the collector opening, the collected sample volumes were converted to precipitation depth in cm. In most cases where sufficient volumes were available, both field and laboratory pH measurements were made. In general, the laboratory pH value is higher than that of the field value due to neutralization of the acid content by alkaline materials in the sample subsequent to collection. By examining the ionic balance and data consistency, a final pH was chosen (usually the laboratory value) and it is from this value that the free hydrogen ion concentration (H_f) was calculated. To obtain total hydrogen ion (H_t) , one must divide the tabulated acidity value which is expressed in $CaCO_3$ equivalent, by a factor of 50. All concentration values are expressed in mg l^{-1}. Not all parameters are reported for all samples due to sample contamination and/or insufficient volume for complete chemical analysis.

It should be pointed out that not all the data reported in Section 1 of the Supplementary Volume are used in the Section 4 data analysis after data screening (see Section 4.1). For completeness, they are all included in the

Supplementary Volume. In this report, these data are analyzed to yield: (i) statistics on sample concentration and deposition, and (ii) correlation and regression relationships using concentration data for the various parameters.

3.2. Statistical Profiling

3.2.1. Concentration Data

During the two year period, there were altogether 2839 samples collected in the network. Some of these had only trace amounts which were not sufficient for chemical analysis. Since top priority was given to pH measurements, there are 2515 reported values. SO_4 and NO_3 belong to the next most frequently measured parameters.

In Table 4, the concentration ranges and means for all data collected from the network have been listed. Both arithmetic and geometric means are given. In general, the latter values are smaller than the former. Volume-weighted mean concentrations are given also for comparison purposes. When a sample was at the detection limit (see Table 3), concentration values corresponding to one-half of the detection limit for the parameter under consideration were used in the calculations.

The average amount of precipitation during a single event over the two year period of network operation was 4.0 mm with a mean pH of 4.3. The most precipitation falling in one event was 66.1 mm. The most acidic event had a pH value of 3.4. Events with pH's above the generally accepted "clean" precipitation value (pH = 5.6) were also observed, and the

most alkaline pH reading was 7.2 As shown by other workers and also discussed later in this report, most of the acidity can be attributed to H_2SO_4 and HNO_3. In this study, maximum SO_4 and $N\text{-}NO_3$ concentrations were 29.3 and 14.1 mg l^{-1} respectively. Average SO_4 and $N\text{-}NO_3$ values were 2.8 and 0.5 mg l^{-1}. Trace metals are of interest from the effects aspect. Maximum values (in mg l^{-1}) observed were: Fe = 3.9.; Cu = 2.5; Ni = 0.9; Pb = 0.5; Zn = 1.7; Al = 2.3; Cr = 0.1 and Cd = 0.03 with most mean values less than or equal to 0.01 mg l^{-1}.

Data for individual stations are also given in Section 2 of the Supplementary Volume for reference. A summary of the acid-related parameter data is given as Table 5. It is seen that the sample with the highest pH value (7.18) was collected at Verner while the most acidic one (3.36) was collected from Capreol. The samples with maximum SO_4 and NO_3 concentrations were collected respectively from Kelly Lake (II) and Coniston.

3.2.2. Deposition Data

A statistical summary of deposition for each event at all stations over the two year period is given in Table 6.

Deposition is calculated by multiplying the concentration (mg l^{-1}) and the precipitation depth (mm) of the sample. All results are expressed in mg m^{-2}. It can be seen that the maximum loading due to some events could be as high as 70 times the mean value (e.g. Ca^{++}). This points to the importance of the concept of episodicity, i.e. a significant portion of the

total loading during a given period may be attributed to a relatively small number of events.

Details of the data from individual stations are given in Section 3 of the Supplementary Volume.

3.2.3. Inter-elemental Relationships

All concentration data from all sites collected over the two-year period were cross-correlated and the results are shown in Table 7. Only those correlation coefficients which are statistically significant at the 99% confidence level are tabulated. The top and bottom values of each entry correspond respectively to the correlation coefficient and the number of data pairs used in the calculation. Fitting the data to a linear relationship $Y = A + BX$ (with X and Y in mg l^{-1} unit), the regression coefficients A and B are obtained and are given in Table 8 as the top and bottom values of the entries.

The data indicate a negative correlation between concentration of most parameters and volume, as has been found by other workers (- see, for example, Granat-reference 4). H_f, H_t, SO_4, NO_3 and NH_4 are in general quite highly correlated. This suggests that H_f (free hydrogen ions) is primarily due to contributions of H_2SO_4 and HNO_3. The fact that a relatively high correlation is found between NH_4 and SO_4, and NH_4 and NO_3 suggests that these three species are in chemical equilibrium, and that the acids collected have been neutralized by ammonia. The high correlation between Na and Cl may indicate the presence of winter road salt. That

Ca, Mg, K and Si correlate well with each other, but not with Na, is a result of the fact that they are all soil-related and that Na has an additional contribution from road salt. The high correlation between Fe, Cu, Ni, Pb and Cd is not surprising in view of the fact that these are good tracers for smelter emissions.

The high correlation between Fe and Al concentrations reflects the fact that both elements have significant soil contributions. The low correlation between Zn and any trace metal is somewhat surprising but could be due to the fact that samples are prone to contamination of Zn, for instance by insects.

A detailed correlation and regression analysis for each station is given in Sections 4 and 5 of the Supplementary Volume.

4. IMPACT OF THE LOCAL SOURCES ON PRECIPITATION QUALITY

4.1 Data Analysis Approach

The approach taken in this report is quite similar to that employed in an earlier publication (3). Basically a two-stage process was used to classify the events, based on a meteorological stratification according to air mass origin and a sector analysis to define the area with potential and observed impact of the local source. Only days for which at least three samples with more than 1 mm precipitation depth were collected were considered. A distinction was made between warm and cold-frontal events, using synoptic weather maps. In most cases, classification was quite straightforward, though occasionally difficulties were encountered because of multiple or occluded fronts. In this report, there are altogether 89 events associated with a warm frontal passage and 96 events associated with a cold frontal passage. Geostrophic trajectories were also calculated to establish air parcel origins on days of interest. Further stratification of samples into those under the "shadow" of the plume and those "background" samples not in the plume shadow was based primarily on local meteorological data. Hourly wind information obtained at both the airport (ground level) and the MOE meteorological tower (114 m level) at Frood Road in Sudbury was compiled and stored in a computer. Plots were generated for each event, showing the Sudbury basin and sampler locations, with the origin centered at INCO. These plots also included upper and lower wind information, as well as chemical concentrations of certain parameters. A plume sector was generated according to the wind sector constructed by the upper and lower hourly mean wind direction for each event. This plume sector should not be confused with the plume width. The

former is an estimate made from the available wind information and is expected to be wider than the latter because it also includes the total area covered by the meandering of the plume. This meteorologically-derived plume sector information was further substantiated by inspecting the SO_4, Cu and Ni concentrations in the precipitation samples. If there were elevated concentrations outside of the sector defined by winds, the sector was expanded to also include the samplers with elevated values. Typically the plume sector is less than 70^{o}. This value differs from the one reported earlier(3) based on a smaller data set, because in the present work, a particular sampler had to be downwind of the source for at least two of the hourly observations during the event in order to be included within the plume sector, whereas in the earlier work there was no such restriction. This changes the average plume sector concentration, but should not affect the deposition calculations. The latter corresponds to the product of concentration and sector area. The narrowing of the plume sector and the corresponding elevation of concentration compensate each other. A summary of the meteorological data is given in Section 6 of the Supplementary Volume.

4.2 Data Interpretation

In the following sections, seven topics will be addressed.

1. Background concentration in precipitation.
2. Relative contribution of local and long-distance transport components to precipitation quality.
3. Dependence of plume constituent concentrations on distance from the local sources.

4. Percentage of local emissions wet-deposited in the Sudbury area.
5. Relative contribution of local and long-distance sources to local wet deposition.
6. Oxidation rate of SO_2 to sulfate under precipitating conditions.
7. Scavenging properties of pollutants by rain as compared to snow.

4.2.1. Precipitation Concentration in Background Samples

Based on weather maps, precipitation events were classified as to whether they were associated with cold or warm frontal passages. Using the sector analysis method described earlier, on a daily basis, all the background samples, i.e. samples collected outside of the plume shadow, were averaged to obtain a daily mean concentration. These daily areal averages were further averaged to yield the results shown in Tables 9 and 10 according to whether the events were associated with warm or cold frontal passages and summer or winter seasons.

In these tables, both the mean concentrations together with the standard deviations are given to indicate the variability of the results. The number of data points (events) is designated as NN. It is seen that, during the study period, the distribution of events into warm and cold frontal passages and winter and summer incidents was quite even. For comparison purposes, the relative concentration ratios are shown as either B/A or A/B in the tables and if the Students - t statistics are significant at the 95% confidence level, the T-T value is marked by an asterisk.

From the relative concentration ratios in Table 9, it is seen that

concentrations associated with cold fronts are usually lower and if they are higher, the increase is not statistically significant. This is not difficult to rationalize, as southerly flows carrying pollutants from large emission sources are usually associated with warm fronts. H_f, H_t (acidity), SO_4, NO_3, NH_4, Pb, Zn are in the fine-particle size range(5,6) and seem to have a long-range transport contribution. The concentration differences of Ca, Mg, K, Fe and Al, which have an important and more local soil source, are also statistically different. This may be a result of different wind-blown dust contributions associated with the two types of frontal passage.

From Table 10, it is seen that, as expected, the concentrations of the soil-derived constituents in winter precipitation are generally lower than those in summer precipitation. The lower winter Ca, Mg and K concentrations reflect the presence of snow cover. The higher Na and Cl concentrations are undoubtedly a result of road salt used in the winter time. It is of interest to note, over the year, that concentrations of SO_4 are higher in the summertime, but those of NO_3 are higher in the wintertime. This observation may be a consequence of different emissions conditions and oxidation and scavenging properties of SO_x and NO_x in the two seasons. This also has a significant implication on control strategy, since the acidity in precipitation may originate from different species in the two seasons. Because of the compensating contribution of SO_4 and NO_3 to acidity, it is noted that the resultant H_f concentration is comparable in the summer and winter seasons.

A detailed backward air parcel trajectory analysis was done for each event to determine the location of the 24 and 48 hours preceeding the

event near Sudbury. The results are expressed in terms of sector of the location of the air 24 and 48 hours prior to the event and are summarized in Tables 11 and 12 respectively. Over the two-year period, air masses associated with the observed precipitation events originated predominantly from the S and SW sectors. The concentration of species such as SO_4, NO_3, H^+ and trace metals that occur in the atmospheric particulate as submicron particles, which have a contribution due to long range transport, are in general higher for the S and SW sectors, which supports the earlier observations regarding warm and cold frontal passages. It should be stressed that because an air parcel does not travel along a straight line to the receptor area (Sudbury), the sector designation refers only to the origin of the air mass 24 hours and 48 hours before and the sector information does not yield any information regarding the immediate or intermediate history of the air mass. It should also be noted that there are problems in predicting back trajectories during frontal passages and therefore there is some uncertainty in the sector of origin calculations for individual events. Because of the averaging over a large number of events in this report, these uncertainties should not change the general conclusion.

4.2.2. Relative Contributions to Precipitation Concentrations due to Local and Distant Sources

A comparison was made of the average precipitation concentrations observed under and outside the plume sector during the smelter operational period. Despite the fact that the background contribution was quite large, with careful sector stratification, it was possible to single out the local source contribution which is compared to the background value in Tables 13

and 14 for the INCO and Falconbridge sources respectively. In these tables, only sampling days when there was a clear assignment to each of the INCO and Falconbridge plumes (i.e., when there was no plume overlap) were considered. The first column lists the parameters of interest. The second and third columns summarize the average background concentrations and plume sector concentrations obtained from the daily means. The fourth and fifth columns give the standard deviations of the corresponding concentrations. The relative ratios of the mean plume to mean background concentrations are summarized as column six for comparison purposes. The total number of data points used in the paired t - test is given as NN in the seventh column with the statistics summarized in the last column. It is seen that for all parameters the difference between plume sector concentrations and background concentrations are statistically significant at the 95% confidence level in the case of INCO. Except for parameters Mg and Na, this is also true for Falconbridge. For most of the smelter-related materials, plume sector to background concentrations ratios are larger than unity. For Ni and Cu, they are an order of magnitude higher in INCO's case. As can be seen, the contribution due to INCO is considerably higher than that of Falconbridge, in qualitative agreement with their respective emission rates. One should also bear in mind the relative locations of the two sources with respect to the network samplers. The network stations surrounded the INCO source relatively uniformly, but coverage was not nearly as good for Falconbridge, most of the sites being south of the source. Because of this, northerly flows tended to be favored in the data analysis for Falconbridge (e.g., for an event with southerly flows, in many cases there was no sampler in the meteorologically-defined plume sector), and so one would expect the

"background" concentrations associated with the Falconbridge and INCO events to be different. Also it should be noted that in the Falconbridge case, data used corresponded to data collected over the two-year study period whereas in INCO's case, due to a strike, samples collected from mid-September, 1978 to early June, 1979 were not used in the analysis reported here due to no plume influence.

4.2.3. Dependence of Plume Concentrations on Distance from the Source

The additional precipitation concentratrion due to plume contribution was correlated with distance from the source using four different expressions:

$$(\text{Conc}) = A + B\text{x}R \qquad (1)$$

$$(\text{Conc}) = A + B/R \qquad (2)$$

$$\ln(\text{Conc}) = A + B\text{x}R \qquad (3)$$

$$\ln(R \text{ x Conc}) = A + B\text{x}R \qquad (4)$$

where (Conc)= additional concentration at distance R

R = distance from the source

A and B are constants

Equation (3) is purely empirical. The others are suggested by mathematical modelling (7) (either directly, or by a rearrangement of terms). The reason behind this type of fitting is to establish an empirical relationship between the additional concentration and the distance from the source, so that wet deposition of the plume constituents can be calculated.

Attempts were made to fit both the individual data points and grouped data. The former procedure is quite straightforward, but in the latter cases (for the INCO and Falconbridge sources respectively) the additional concentration data were grouped over different distance intervals from the source. Because of the limitations imposed by the network station distribution, in the case of INCO, mean distances were selected at 5 Km (representing the interval 3-6 Km), 10 Km (9-11 Km), 15 Km (14-16 Km), 20 Km (17-24 Km), 30 Km (27-32 Km), and 40 Km; (35-50 Km) and in the case of Falconbridge, 8 Km (6-11 Km), 17 Km (17-19 Km), 23 Km (21-24 Km), 32 Km (28-33 Km), 40 Km (38-41 Km) and 50 Km. In the present case, every value of the additional concentration, be it positive or negative, was used in the averaging step to obtain the average additional concentration for the corresponding interval. This takes into account the "noise" (random errors) associated with sampling and may be more appropriate. The approach taken in this report was slightly different from that used in the previous analysis (3), in which negative additional concentrations were replaced by zero before averaging. The mean concentration results are given in Tables 15 and 16.

Tables 17 to 20 summarize the correlation (COR) and regression (A and B) coefficients of the eight combinations (individual data points vs. grouped data using the four formulae) for the two sources. Examining the results in Tables 17 to 20 more closely, it is seen that the data from the INCO source fit the expressions better than those from the Falconbridge source. This is partially due to the fact that there are more data points for the former source and the magnitude of the source strength is larger. This point should be borne in mind when one comes to the deposition

calculations in Section 4.2.4. Note that there is a great deal of scatter in the data due to a number of factors -sampling errors, the inherent variability in precipitation data (see, for example, references 2 and 4), and the fact that the plume sector only includes a potential plume effect (i.e., a particular sampler downwind of the source for part of the storm may not necessarily have been noticeably affected by the source).

It is shown later from the deposition calculations that within a 40 Km limit from the source where the data were collected, the fits with grouped data and individual points yield comparable results. It is seen that expression (2) yielded best regression for trace metals which are originated from local sources. The high correlation using expression (4) for the major ions, which are greatly affected by long range transport, may be fortuitous. It is an artifact because the concentration change as a function of distances is small for these parameters and essentially what was fitted was ln R + ln constant versus R. Therefore, regression coefficients determined from expression (2) with grouped data were used later in the subsequent calculations.

The results can be broadly classified into three categories:

1) acid-base related species, e.g., H_f, H_t, SO_4, NO_3 and NH_4;
2) soil-originated species, e.g., Ca, K, Mg, and Na;
   and
3) smelter-originated trace metals, e.g., Fe, Cu, Ni, Pb, Zn, Al, Cr, and Cd.

Note that there is some overlap. For example, Fe and Al are contributed by both the smelter and soil.

Parameters that originate from soil are of secondary interest compared to those which originate primarily from the smelter source. The species related to acid-base equilibria yield less satisfactory relationships compared to those of the trace metals. This is consistent with similar observations reported earlier (3).

4.2.4. Percentage of Local Emissions Wet Deposited

Wet deposition results were related to emissions from the local sources. Emission data on SO_2 were obtained from INCO and Falconbridge based on either in-stack SO_2 continuous monitor data or mass balance results. The INCO smelter and Iron Ore Recovery Plant data were available on a daily basis, but those from Falconbridge were only reported on a monthly basis. Because of occasional malfunctioning of the SO_2 monitor, the INCO daily data were sometimes incomplete. Low level emissions data were not available and were estimated as comprising 2% of the smelter stack values from the best currently available information (8). In Section 7 of the Supplementary Volume daily SO_2 emissions (in metric tons per day) from the two sources are summarized for all event days (from 0800-0800 hours) whenever they are available. These SO_2 data were also used, with the particulate-to-SO_2 ratios determined in previous studies for these two sources (5,6), to obtain the corresponding particulate emissions rates* (9) which are also given in Section 7 of the Supplementary Volume. A list of the particulate-to-SO_2 ratios is given in Table 21. The hydrogen ion emission rates were estimated by assuming that all sulfates were emitted as sulfuric acid.

---

* There are limited particulate emission measurements made at the INCO two 45 m stacks, and also estimates of the INCO smelter low level emissions, which suggest that emissions of particulate Fe and Cu might be significant compared to those from the 381 m chimney at these two sources respectively (21). However, due to the unknown quality of these mesurements, these values were not included in the current calculations.

Using the above expressions relating the additional concentration and distance, wet deposition patterns of the plume constituents of the two sources were calculated for INCO and Falconbridge respectively according to:

$$DEP_{av} = D_{av}\int_{R=0}^{40Km}(C_{add}\, dA_{plum});$$

where DEP_{av} = average areal deposition through wet scavenging

D_{av} = average precipitation depth (mm)

C_{add} = average additional concentration due to interaction of plume and precipitation (in mg l^{-1} unit)

A_{plum} = area encompassed by the plume sector

Similar calculations were carried out using each of the relationships reported in Section 4.2.3., with grouped as well as individual data. It was found that they all yielded comparable results. Deposition calculations were made by use of expression (2) relating the concentration and distance as 1/R, together with grouped data. The average precipitation depths of all INCO and Falconbridge events used in the deposition calculations were 7.4 and 8.9 mm respectively. Average plume sector angles varied slightly for the two sources and were 64.0^{o} and 67.9^{o} respectively.

The wet deposition results are summarized in Tables 22 and 23 for INCO and Falconbridge. Based on average precipitation durations, daily emission data were prorated to yield average emissions during the precipitation period for comparison purposes and are listed under column 4. The average event durations for the two sources with all data were: INCO

events - 10.5 hours; and Falconbridge events - 10.8 hours. The percentage of local emissions which were wet-scavenged within 40 Km are tabulated in column 6.

It is seen in Table 22 that, up to a distance of 40 Km from the source, except for total sulfur, 23 to 100% of the INCO emissions appear to be scavenged during precipitation events. The results for H_f and SO_4 should however be interpreted bearing in mind that the materials deposited may correspond not only to the primary emissions but also to secondary production of sulfuric acid due to oxidation of SO_2. Therefore, more appropriately, the percentage of total emitted sulfur that is scavenged is reported, and this corresponds to a small percentage only. The percentage of metals scavenged is quite high and approaches total washout for Cu. Similar results to the above have been reported by other workers (10,11).

Table 23 summarizes the Falconbridge results. The percentage of the emissions scavenged in the Falconbridge case was higher than that for INCO, and in almost all cases the wet deposition was greater than the emission rate. This improbable result is due to the relatively poor fit of the additional concentration with distance data and due to the poor network coverage - the network was designed to study primarily the INCO source. It is also suspected that some of the observations in the Falconbridge case were influenced by INCO emissions. Therefore, these results should be regarded with considerable caution.

4.2.5. Relative Contribution of Local vs. Long-Range Transport Components to the Local Wet Deposition.

In Tables 22 and 23, the contribution to wet deposition due to INCO and Falconbridge, as compared to the background deposition, within a 40 Km radius of Sudbury, is also given. The background deposition was calculated by using the mean background concentration and an average precipitation depth of 7.4 and 8.9 mm respectively for the two sources. It is seen that on average, all of the deposition due to the INCO source corresponds to 5 to 20% of the total with the exception of Cu, Ni, and Cd, with the first two species contributing as much as 70%. The Cu and Ni result are not surprising considering the fact that plume concentrations of these species have been observed to be very high with respect to the background (See Table 13).

An upper limit for the Falconbridge contribution was established by assuming that except for S and Cd all pollutants are scavenged within 40 Km from the source (i.e., column 4 rather than column 5 in Table 23 was used in the calculations). The results are shown in the final column, and indicate that the contribution due to this smelter to the total deposition is in general smaller than that from the INCO smelter.

It is worthwhile pointing out that, farther downwind from the source, the plume sector concentration will be lower, and the relative contribution to the total deposition due to the smelter sources will be even smaller than the above values.

4.2.6. Oxidation Rate of SO_2 to SO_4 under Wet Conditions

Using the information on the fraction of SO_4 scavenged by precipitation, one can attempt to estimate the wet oxidation rate of sulfur dioxide to sulfate. This can be done knowing the emission rates of SO_2 and SO_4, and the scavenging efficiency of SO_4. It has been recognized that particles of the same size range have similar scavenging properties. From the particle sizing work carried out at the INCO 381 m chimney plume, it was found that both SO_4 and Pb fall into the same size category. They both have an average mass median diameter of approximately 1 um (6). This suggests that Pb could be used as a reference material to infer sulfate scavenging efficiency. Results in Table 22, indicate that the percentages of Pb and SO_4 scavenged corresponded to 33% and 48% respectively. Assuming that the primary and secondary sulfates are scavenged equally efficiently by precipitation, we can attribute the difference of the two values, i.e., 48% -33% = 15% secondary sulfate scavenged. Knowing that the sulfate scavenging efficiency is equal to that of Pb, i.e., 33%, we can then infer that the amount of secondary sulfate formed is equal to 15% x 100/33 = 45% of that of the primary sulfate. Relating this information to that of the SO_4 emissions with respect to SO_2, (i.e., SO_4/SO_2 = 1.8%), we can determine the percentage of SO_2 converted to SO_4 under wet conditions within a distance of 40 Km. Using an average wind speed of 5 m s^{-1}, the 40 Km is calculated to correspond to a plume age of 2.2 h. With the above assumptions, it was found that the percentage of SO_2 converted to SO_4 under wet conditions over 2.2 h is 0.8%. In other words, the oxidation rate is less than 0.5% h^{-1}.

The same procedure can be repeated for the rain and snow using results in Table 26. It is found that the oxidation process is faster in the summer/rain than the winter/rain-snow conditions with rates of approximately 1% h^{-1} and close to zero respectively.

The relatively low inferred oxidation rate is of particular interest as it is inconsistent with the high oxidation rates under wet conditions suggested by some other researchers (12-16).

4.2.7 Scavenging by Rain as Compared to Snow

Using the expressions given in Section 4.2.4 summer and winter deposition rates were calculated separately for INCO and are shown in Tables 24 and 25. For the summer (rain only), the average INCO plume sector was 57.4^{o}; precipitation duration was 7.7 h; and precipitation depth was 8.6 mm. For the winter (mixed rain and snow), the average INCO - plume sector was 68.0^{o}; precipitation duration was 12.2 h and precipitation depth was 6.4 mm. Because of the uncertainty in the Falconbridge results, no corresponding calculations are included for this smelter.

In Table 24, the percentage of the INCO emissions removed within 40 Km of the source was compared for winter and summer events. The scavenging of plume constituents by precipitation was not uniform throughout the year. For acid and sulfur, the scavenging seems to be more efficient in the summertime, whereas in the case of trace metals (except Pb, Cr and Zn which are in the fine-particle size range), the reverse seems to be true. The sulfur results are consistent with what was reported by Summers and Hitchon (17). The results for trace metals suggest more

efficient removal by snow than by rain. This was especially true for metals (e.g. Fe, Al, etc.) in the coarse size range. However, it is difficult to determine if these differences are significant.

For mathematical model input, scavenging coefficients can be calculated by using the following simple relation:

$$C_t = C_o e^{-\lambda t}$$

Where C_t = concentration at time t

C_o = initial concentration

λ = scavenging coefficient

t = time

The fraction of emissions removed from the plume, which can be obtained from the experimental data, is then related to by the equation:

$$\text{fraction removed} = 1- e^{-\lambda t}$$

Using an average wind speed of 5 m s^{-1}, a 40 Km radius corresponds to a plume age of 8,000 seconds. The scavenging coefficients (in units of s^{-1}) calculated using information given in Table 24 for the INCO 381 m chimney plume constituents for the summer (May to October) and winter (November to April) are compared with those for all year round and these results are summarized in Table 26. As can be seen, the values are typically on the order of 10^{-4} and 10^{-5} s^{-1} and are quite comparable to those reported in the literature (18).

5. CONCLUSIONS

An event precipitation network was operated in the Sudbury area from June, 1978 to May, 1980 by the Air Resources Branch to quantify the relative contribution of local smelter emissions from INCO and Falconbridge to precipitation quality and pollutant deposition in the local area. Statistical analysis of the two-year data base has been performed. Further, the data have been stratified meteorologically and according to whether or not the samples have been influenced by the plumes. From the analysis of data, the following conclusions are reached.

- The geometric mean pH of the 2515 precipitation samples was 4.3. The most acidic sample had a pH value of 3.4 and the most alkaline one had a pH of 7.2

- Most of the precipitation acidity can be attributed to H_2SO_4 and HNO_3. In this study, maximum SO_4 and $N\text{-}NO_3$ concentrations were 29.3 and 14.1 mg l^{-1} respectively. Geometric mean SO_4 and $N\text{-}NO_3$ concentrations were 2.8 and 0.5 mg l^{-1} respectively, suggesting that sulfuric acid is 1.6 times more important than nitric acid to acidity.

- Maximum concentrations (in mg l^{-1}) of trace metals observed were: Fe = 3.9, Cu = 2.5, Ni = 0.9, Pb = 0.5, Zn = 1.7, Al = 2.3, Cr = 0.1, and Cd = 0.03. Most of the mean values were less than or equal to 0.01 mg l^{-1}.

- Background precipitation concentrations were usually lower during cold frontal precipitation than during warm frontal storms.

- The concentration of the soil-derived constituents (eg. Al, Fe, Si) in winter precipitation was generally lower than that in summer precipitation.

- The concentrations of SO_4 in precipitation were higher in the summertime than in the wintertime. $NO_3^=$ concentrations had the opposite seasonal variation. This observation may be a consequence of different emission conditions, and oxidation and scavenging properties of SO_x and NO_x in the two seasons. Because of the compensating contribution of SO_4 and NO_3 to acidity, it was found that the resultant acid concentrations were comparable in the two seasons.

- Precipitation concentrations of species such as H_f, SO_4, NO_3, and trace metals in the small-particle size range, which had a contribution due to long range transport, were in general higher from the S and SW sectors This supports the observations regarding relative concentrations during warm and cold frontal passages.

- It was possible to single out the local source contribution from that of the background. The downwind precipitation concentrations of smelter-related constituents were significantly higher than those upwind. Those of Ni and Cu were on average a factor of 30 higher. The contribution due to INCO is considerably greater than that of Falconbridge, in qualitative agreement with their respective emission rates.

- Elevated concentrations relative to background were observed in sectors downwind of the local smelter sources. Up to a distance of 40 Km from the source, except for total sulfur, 23 to 100% of the INCO emissions appear to be scavenged during precipitation events. The percentage of the

emissions scavenged was higher for Falconbridge than that for INCO, and in almost all cases the wet deposition was greater than the emission rate. This reflects the relatively poor network coverage and the possibility of interferences due to INCO emissions.

- On average, the deposition within 40 Km of Sudbury due to the INCO source corresponded to 5 to 20% of the total, with the exception of Cu, Ni and Cd. The first two species contributed as much as 70%.

- Wet oxidation rate of SO_2 to SO_4 under wet conditions was found to be less than 0.5% h^{-1} assuming both SO_4 (primary and secondary) and Pb are scavenged equally efficiently because they are of similar size range.

- Scavenging of plume constituents was not uniform throughout the year. For the acid and sulfur compounds, the scavenging seems to be more efficient in the summertime, whereas in the case of trace metals (except Pb, Cr and Zn which are in fine-particle size range), the reverse seems to be true. All scavenging coefficients were typically in the order of 10^{-4} to $10^{-5}\ s^{-1}$.

REFERENCES

1. Chan, W.H., R.J. Vet, C.U. Ro, M.A. Lusis and A.J.S. Tang, "Precipitation Quality and Wet Deposition in the Sudbury Basin: Sudbury Environmental Study Cumulative Precipitation Network Results", Ontario Ministry of the Environment, Air Resources Branch Report # ARB-04-82-ARSP (1982).

2. "An Analysis of the Sudbury Environment Study Network Precipitation Acidity Data. June-September, 1978", Ontario Ministry of the Environment, Air Resources Branch Report, February, (1979).

3. Chan, W.H., C.U. Ro, M.A. Lusis and R.J. Vet., "An Analysis of the Impact of INCO Emissions on Precipitation Quality in the Sudbury Area" Ontario Ministry of the Environment, Air Resources Branch Report #ARB-TDA-35-80, May (1980).

4. Granat, L., Atmos. Environ., 12, 413, (1978).

5. Chan, W.H., R.J. Vet, G.B. Skelton and M.A. Lusis, "Size Distribution and Emission Rate Measurements of Particulates in the 93 m Falconbridge Smelter Stack Plume, 1979", Ontario Ministry of the Environment, Air Resources Branch Report #ARB-TDA-57-80 (1982).

6. Chan, W.H., R.J. Vet, M.A. Lusis and G.B. Skelton, "Size Distribution and Emission Rate Measurements of Particulates in the INCO 381 m Chimney and Iron Ore Recovery Plant Stack Plumes, 1979-80", Ontario Ministry of the Environment, Air Resources Branch Report #ARB-TDA-62-80 (1982).

REFERENCES (CONT'D)

7. Venkatram, A., B.E. Ley and S.Y. Wong., "A Statistical Model to Estimate Long-Term Concentrations of Pollutants Associated with Long-Ragne Transport and Its Application to Emissions from the Sudbury Region." Ontario Ministry of the Environment, Air Resources Branch Report (1982).

8. Fitz, L. and R. Potvin, MOE, Northeastern Region, Personal Communication (1981).

9. Chan, W.H., R.J. Vet, M.A. Lusis, J.E. Hunt and R.D.S. Stevens, Atmos. Environ., 14, 1201 (1980).

10. Wiebe, A. and D.M. Whelpdale, Precipitation Scavenging from a Tall Stack Plume, Proceedings of the 1974 Precipitation Scavenging Symposium, Champaign, Illinois, October 14-18 (1974).

11. Muller, E.F. and J.R. Kramer, Precipitation Scavenging in Central and Northern Ontario, Proceedings of the 1974 Precipitation Scavenging Symposium, Champaign, Illinois, October 14-18 (1974).

12. Hegg, D.A. and P.V. Hobbs , Atmos. Environ., 12, 241 (1978)

13. Newman, L. "General Considerations on How Rainwater Must Obtain Sulfate, Nitrate and Acid", Internat. Symp. on Sulfur Emissions and the Environment, London, May 8-10. (1979).

14. Hales, J.M. and M.T. Dana J. Appl. Meteorol., 18, 294 (1979).

REFERENCE (CONT'D)

15. McNaugton, D.J. and B.C. Scott, J. Air Poll. Control Assoc., 30, 272 (1980).

16. Scott, B.C., "Predicitons of In-Cloud Conversion Rates of SO_2 and SO_4 Based on a Simple Chemical and Dynamical Model", 2nd Joint Conf. on Applications of Air Pollut. Meteorol. and 2nd Conf. on Industrial Meteorol., New Orleans, March 24-28 (1980).

17. Summers, P.W. and B. Hitchon, JAPCA 23, 194 (1973).

18. McMahon, T.A. and P.J. Denison, Atmos. Environ., 13, 571 (1979).

19. Chan, W.H., F. Tomassini and B. Loescher, to be published (1982).

20. Loescher, B., personal communication (1981).

21. Ozvacic, V., "Emissions of Sulphur Oxides, Particulates and Trace Elements in Sudbury Basin", Report #ARB-ETRD-09-82, Air Resources Branch, Ontario Ministry of the Environment (1982).

TABLE 1: SES EVENT PRECIPITATION STATIONS - JUNE 1978 - MAY 1980

STATION NO.	STATION	ELEVATION	LATITUDE	LONGITUDE	UTM EASTING	UTM NORTHING	UTM NORMAL
1	RAMSEY	1400'	47 26'33"	82 20'15"	399400	5255100	LC 9955
2	BURWASH	750'	46 15'46"	80 48'48"	514600	5123000	NB 1422
3	NEW SUDBURY	925'	46 31'55"	80 55'05"	506400	5153300	NB 0653
4/5	LONG LAKE	850'	46 24'37"	80 59'36"	500500	5139400	NB 0039
6	WANUP	780'	46 24'06"	80 50'53"	511700	5138400	NB 1138
7	LIVELY	800'	46 26'09"	81 08'05"	489600	5143000	MB 8943
8/9	AZILDA	905'	46 32'40"	81 07'35"	490400	5154400	MB 9054
10	SKEAD	925'	46 40'08"	80 45'00"	519200	5168000	NB 1968
11	McCHARLES LAKE	850'	46 22'43"	80 15'20"	480500	5136300	MB 8036
12	WINDY LAKE	1200'	46 37'16"	81 27'20"	465000	5163000	MB 6563

SES EVENT PRECIPITATION STATIONS - JUNE 1978 - MAY 1980

STATION NO.	STATION	ELEVATION	LATITUDE	LONGITUDE	UTM EASTING	UTM NORTHING	UTM NORMAL
13	LAKE WANIPATEI	900'	46 47'55"	80 45'05"	519200	5182600	NB 1983
14	VERNER	675'	46 25'38"	80 07'57"	567000	5139800	NB 6740
15	NORTH BAY (CALLANDER)	625'	46 12'35"	79 22'04"	626400	5118550	PB 2618
16	KILLARNEY	700'	46 00'56"	81 23'50"	469300	5095700	MA 6996
17	CHARLTON STATION	725'	47 49'30"	80 02'45"	571500	5297300	NC 7297
18/19	MARKSTAY	800'	46 30'25"	80 36'00"	530700	5150200	NB 3150
20	PANACHE LAKE	750'	46 16'27"	81 20'42"	473400	5124400	MB 7324
21	THESSALON	885'	46 15'35"	83 33'45"	302500	5125600	LB 0325
22	LAURENTIAN UNIV.	900'	46 28'08"	80 58'45"	501700	5145700	NB 0246
23	GRUNDY PARK	600'	45 55'22"	80 33'45"	534100	5085350	NA 3485

SES EVENT PRECIPITATION STATIONS - JUNE 1978 - MAY 1980

STATION NO.	STATION	ELEVATION	LATITUDE	LONGITUDE	UTM EASTING	UTM NORTHING	UTM NORMAL
24	CAPREOL	1175'	46 42'10"	80 55'25"	505800	5172100	NB 0672
25	CREIGHTON	950'	46 27'10"	81 10'46"	486200	5144500	MB 8644
26	KELLY LAKE	850'	46 27'05"	81 02'30"	497700	5143900	MB 9844
27	KELLY LAKE	900'	46 25'40"	81 05'00"	493600	5141300	MB 9441
28	DOWLING	900'	46 35'28"	80 21'05"	473150	5159450	MB 7359
29	CHELMSFORD	900'	46 33'32"	81 13'25"	482800	5155950	MB 8356
30	CONISTON	850'	46 29'29"	80 51'08"	511400	5148500	NB 1185
31	BLIND RIVER	650'	46 11'45"	82 55'50"	356200	5117600	LB 5176
32	WORTHINGTON	850'	46 20'25"	81 30'38"	460700	5130700	MB 6131
33	FROOD ROAD	950'	46 30'05"	81 00'36"	499250	5149200	MB 9949

SES EVENT PRECIPITATION STATIONS - JUNE 1978 - MAY 1980

STATION NO.	STATION	ELEVATION	LATITUDE	LONGITUDE	U T M		
					EASTING	NORTHING	NORMAL
34	NORTH BAY	725'	46 19'45"	79 28'55"	617900	5131500	PB 1832
35	NOELVILLE	650'	46 08'00"	80 25'20"	545000	5108800	NB 4509
36	ST. CHARLES	750'	46 21'56"	80 25'04"	544950	5134550	NB 4534
37	GARSON	950'	46 32'50"	80 53'25"	508600	5154600	NB 0955
38	HWY 144	1000'	46 31'45"	81 04'35"	494100	5152600	MB 9453
39	BLACK LAKE ROAD	825'	46 22'30"	81 07'04"	490900	5135550	MB 9136
40	VAL CARON	950'	46 36'45"	81 01'45"	498300	5162000	MB 9862
41	BLEZARD VALLEY	950'	46 35'35"	81 03'55"	495150	5161500	MB 9562
42	HANMER	950'	46 38'25"	81 00'50"	500370	5165000	NB 0065

TABLE 2
Summary of Network Operations

Station		Number of Samples with Volume Measured	Number of Samples with pH Measured	First and Last Sampling dates
1	Ramsey	58	54	June 21/78 - Oct. 23/79
2	Burwash	213	208	June 27/78 - May 18/80
3	New Sudbury	31	25	June 26/78 - Apr. 14/79
4/5	Long Lake I and II	122	105	June 26/78 - May 30/80
6	Wanup	234	216	June 22/78 - May 19/80
7	Lively	14	10	July 12/78 - Oct. 1/78
8/9	Azilda I and II	66	52	Aug. 18/78 - Oct. 29/79
10	Skead	18	17	July 22/78 - Oct. 1/78
11	McCharles Lake	44	42	June 26/78 - Apr. 15/79
12	Windy Lake	15	7	July 7/78 - Aug. 28/78
13	Lake Wanapatei	13	5	July 7/78 - Aug. 17/78
14	Verner	186	160	July 8/78 - May 19/80
15	Callander	2	1	Aug. 16/78 - Aug. 24/78
16	Killarney	17	10	July 11/78 - Aug. 24/78
17	Charlton Station	2	2	July 15/78 - Aug. 17/78
18/19	Markstay I and II	57	53	July 8/78 - Oct. 28/79
20	Lake Panache	131	114	June 6/78 - May 30/80
21	Thessalon	24	18	July 18/78 - Jan. 5/79
22	Laurentian University	179	160	July 21.78 - May 30/80
23	Grundy Park	20	16	July 13/78 - Oct. 17/78
24	Capreol	68	59	Aug. 29/78 - Oct. 29/79
25	Creighton	182	170	Oct. 17/78 - May 19/80
26	Kelly Lake I	118	109	May 28/79 - May 18/80
27	Kelly Lake II	121	114	June 20/79 - May 30/80
28	Dowling	140	117	May 13/79 - May 19/80
29	Chelmsford	21	17	May 17/79 - Oct. 21/79
30	Coniston	105	95	June 9/79 - May 19/80
31	Blind River	46	40	May 18/79 - Oct. 28/79
32	Worthington	50	46	May 11/79 - Oct. 28/79
33	Frood Road	0	0	July 1/79 - July 15/79
34	North Bay	43	36	May 11/79 - Sept. 14/79
35	Noelville	122	107	May 10/79 - May 31/80
36	St. Charles	49	38	May 19/79 - Oct. 29/79
37	Garson	110	91	June 1/79 - May 19/80
38	Highway 144	116	105	June 20/79 - May 30/80
39	Black Lake	38	33	June 21/79 - Nov. 2/79
40	Val Caron	23	22	March 23/80 - May 19/80
41	Blezard Valley	23	23	April 3/80 - May 19/90
42	Hanmer	20	17	April 3 - May 30/80

TABLE 3

Details of Precipitation Sample Analyses

Parameter	Analysis Method	Detection Limit (mg l^{-1})
pH (for H_f determination)	Radiometer	0.1 pH unit
Total Acidity (for H_t determination)	NaOH titration to pH 8.3; results presented as mg $CaCO_3$ l^{-1}	0.08
SO_4	Ion Chromatography	0.04*
$N\text{-}NO_3$	Ion Chromatography	0.01*
Cl	Ion Chromatography	0.04*
F	Ion Chromatography	0.04*
$N\text{-}NH_4$	Automated phenate-hypochlorite method	0.008*
Ca	Flame atomic absorption	0.02*
Na	Flame atomic absorption	0.02*
K	Flame atomic absorpiton	0.02*
Mg	Flame atomic absorption	0.02*
Zn**	Flame atomic absorption	0.001
Fe	Flameless atomic absorption	0.001
Ni**	Flameless atomic absorption	0.001
Cu**	Flameless atomic absorption	0.001
Pb**	Flameless atomic absorption	0.001
Al	Flameless atomic absorption	0.005
Cr**	Flameless atomic absorption	0.0005
Cd**	Flameless atomic absorption	0.0001

* Values correspond to lowest values reported.

** Analysed by ICP in 1980

TABLE 4

SES EVENT PRECIPITATION CONCENTRATION DATA STATISTICAL SUMMARY

EVENT SAMPLING ANALYSIS RESULTS

SUDBURY ENVIROMENTAL STUDY

THE STATISTICAL TABLE - ALL DATA
(CONCENTRATION)

ALL STATIONS
STATISTICAL PERIOD :780501-800531

PAGE : 1

			(MG/L)									
	VOL.	PH	ACIDITY	HF	HT	SO4	N-NO3	N-NH4	CL	CA	MG	NA
SAMPLE SIZE :	2839.	2515.	1708.	2515.	1708.	2372.	2382.	2209.	2322.	1977.	1996.	1971.
MAXIMUM :	9335.	7.18	25.85	0.437	0.517	29.25	14.09	6.180	13.80	4.00	0.77	4.40
MINIMUM :	7.	3.36	1.09	0.000	0.022	0.10	0.01	0.003	0.005	0.005	0.002	0.005
RANGE :	9328.	3.82	24.76	0.436	0.495	29.15	14.08	6.177	13.80	3.99	0.77	4.39
ARITH. MEAN :	981.	++++	5.86	0.072	0.117	3.95	0.67	0.468	0.414	0.299	0.052	0.164
ARITH. STD. DEV :	1085.	++++	3.15	0.058	0.063	3.38	0.69	0.457	0.795	0.360	0.077	0.312
GEOM. MEAN :	563.	4.27	5.16	0.051	0.103	2.84	0.47	0.304	0.21	0.17	0.03	0.08
GEOM. STD. DEV. :	1.13	0.10	0.50	1.002	0.502	0.86	0.89	0.999	1.08	1.10	1.13	1.17
1ST QUARTILE :	260.	4.03	3.64	0.033	0.073	1.65	0.28	0.162	0.11	0.08	0.01	0.04
2ND QUARTILE :	617.	4.22	5.14	0.060	0.103	3.10	0.49	0.320	0.20	0.18	0.03	0.08
3RD QUARTILE :	1292.	4.48	7.17	0.093	0.143	5.15	0.84	0.630	0.38	0.37	0.06	0.16
VOL. WGT. MEAN :		4.28*	5.57	0.068	0.111	3.52	0.51	0.392	0.21	0.25	0.04	0.10

***** : INSUFFICIENT DATA
++++ : NOT CALCULATED
* : CALCULATED FROM THE CORRESPONDING HF VALUE

TABLE 4
continued...

EVENT SAMPLING ANALYSIS RESULTS

SUDBURY ENVIROMENTAL STUDY

THE STATISTICAL TABLE - ALL DATA
(CONCENTRATION)

ALL STATIONS
STATISTICAL PERIOD :780501-800531

		(MG/L)										
		K	SI	F	FE	CU	NI	PB	ZN	AL	CR	CD
SAMPLE SIZE	:	1992.	420.	2253.	2046.	2046.	2046.	2046.	2042.	2012.	2044.	2042.
MAXIMUM	:	1.85	0.35	0.79	3.940	2.470	0.932	0.500	1.670	2.310	0.0810	0.0300
MINIMUM	:	0.005	0.020	0.001	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0003	0.0001
RANGE	:	1.85	0.33	0.79	3.939	2.469	0.931	0.499	1.669	2.309	0.0807	0.0300
ARITH. MEAN	:	0.09	0.05	0.04	0.103	0.035	0.016	0.019	0.021	0.054	0.0007	0.0007
ARITH. STD. DEV	:	0.15	0.04	0.05	0.220	0.132	0.059	0.027	0.065	0.108	0.0028	0.0019
GEOM. MEAN	:	0.04	0.04	0.02	0.043	0.005	0.002	0.012	0.010	0.021	0.0004	0.0003
GEOM. STD. DEV.	:	1.20	0.58	0.93	1.291	1.777	1.725	0.902	1.089	1.518	0.7888	1.3167
1ST QUARTILE	:	0.02	0.02	0.02	0.019	0.001	0.000	0.007	0.006	0.008	0.0003	0.0001
2ND QUARTILE	:	0.04	0.05	0.02	0.042	0.003	0.001	0.012	0.011	0.024	0.0003	0.0002
3RD QUARTILE	:	0.09	0.05	0.04	0.093	0.013	0.006	0.021	0.019	0.064	0.0005	0.0006
VOL. WGT. MEAN	:	0.06	0.05	0.03	0.075	0.020	0.010	0.014	0.015	0.045	0.0006	0.0005

***** : INSUFFICIENT DATA
++++ : NOT CALCULATED

TABLE 5: SUMMARY OF ACID-RELATED PARAMETER DATA

Station	n*	pH Max.	pH Min.	pH Geom. Mean	SO_4 Max. (mg l^{-1})	SO_4 Min. (mg l^{-1})	SO_4 Geom. Mean (mg l^{-1})	$N\text{-}NO_3$ Max. (mg l^{-1})	$N\text{-}NO_3$ Min. (mg l^{-1})	$N\text{-}NO_3$ Geom. Mean (mg l^{-1})
All	2515	7.18	3.36	4.27	29.25	0.10	2.84	14.09	0.01	0.47
Ramsey	54	5.97	3.53	4.34	17.5	0.28	1.76	1.42	0.04	0.23
Burwash	208	5.45	3.45	4.20	16.75	0.20	2.45	3.55	0.04	0.49
New Sudbury	25	4.91	3.64	4.20	10.30	0.35	2.42	1.80	0.06	0.41
Long Lake	105	6.02	3.47	4.26	13.75	0.25	2.78	2.90	0.04	0.48
Wanup	216	6.27	3.51	4.31	16.25	0.20	2.65	4.00	0.02	0.49
Lively	10	4.64	3.60	4.10	7.20	1.10	3.03	0.84	0.10	0.34
Azilda	52	5.82	3.53	4.29	13.0	0.20	2.99	6.50	0.01	0.43
Skead	17	5.03	3.86	4.25	10.10	0.60	2.63	1.00	0.04	0.27
McCharles L.	42	6.30	3.48	4.28	10.80	0.20	2.65	3.80	0.02	0.39
Windy L.	7	4.63	3.77	4.13	11.20	1.00	3.61	0.87	0.14	0.34
L. Wanipatei	5	4.85	3.54	4.35	3.90	1.45	2.47	0.84	0.15	0.32
Verner	160	7.18	3.52	4.30	12.85	0.25	2.31	5.50	0.03	0.47
Callandar	1	4.28	4.28	-	1.60	1.60	-	0.08	0.08	-
Killarney	10	5.55	3.73	4.23	6.90	1.30	3.53	1.18	0.30	0.55
Charleton Stn	2	5.36	4.87	5.11	0.90	0.40	0.60	0.09	0.06	0.07
Markstay	53	5.27	3.44	4.22	13.35	0.40	3.52	1.90	0.03	0.36
L. Panache	114	6.65	3.47	4.24	19.01	0.20	2.30	4.35	0.03	0.46
Thessalon	18	5.28	3.82	4.37	10.40	0.66	2.52	1.34	0.18	0.45
Laurentian U.	160	6.29	3.44	4.21	20.00	0.40	3.19	6.00	0.05	0.51
Grundy Pk	16	4.75	3.59	4.00	7.15	1.20	4.20	1.17	0.15	0.59
Capreol	59	6.85	3.36	4.18	15.00	0.30	3.71	5.05	0.01	0.42
Creighton	170	6.31	3.41	4.30	27.70	0.10	2.71	4.40	0.04	0.48
Kelly L (I)	109	6.44	3.51	4.26	24.00	0.70	3.67	3.70	0.04	0.53
Kelly L. (II)	114	6.42	3.56	4.25	29.55	0.34	3.67	3.55	0.04	0.54
Dowling	117	6.58	3.45	4.33	15.75	0.15	2.18	5.70	0.01	0.44
Chelmsford	17	7.15	3.73	4.60	15.65	1.20	4.27	0.95	0.04	0.32
Coniston	95	5.99	3.59	4.28	18.45	0.30	2.79	14.09	0.03	0.51
Blind River	40	6.83	3.51	4.41	28.00	0.90	3.78	2.60	0.05	0.48
Worthington	46	6.66	3.43	4.24	19.50	0.45	4.01	3.60	0.06	0.53
North Bay	36	6.58	3.52	4.31	19.10	1.50	4.21	2.06	0.05	0.45
Noelville	107	5.90	3.61	4.32	19.40	0.20	2.22	3.85	0.01	0.49
St. Charles	38	5.06	3.60	4.22	14.05	0.50	3.72	1.60	0.07	0.46
Garson	91	6.44	3.55	4.30	17.25	0.25	3.36	4.40	0.06	0.59
Hwy 144	105	6.47	3.48	4.28	28.35	0.40	3.41	3.52	0.06	0.49
Black L. Rd.	33	6.44	3.51	4.18	10.40	1.30	3.98	1.46	0.08	0.53
Val Caron	22	5.02	3.85	4.30	6.60	0.70	2.70	2.02	0.08	0.38
Blezard Valley	23	5.49	3.84	4.35	7.65	0.65	2.63	2.20	0.06	0.32
Hanmer	17	4.97	3.87	4.29	6.20	0..50	2.53	3.19	0.05	0.34

* The number of samples with pH measurements. This could be larger than that with SO_4 and/or NO_3 analysis.

TABLE 6

SES EVENT PRECIPITATION DEPOSITION DATA STATISTICAL SUMMARY

EVENT SAMPLING ANALYSIS RESULTS

SUDBJRY ENVIROMENTAL STUDY

THE STATISTICAL TABLE - ALL DATA
(DEPOSITION)

ALL STATIONS
STATISTICAL PERIOD :780501-800531

							(MG/M**2)					
	VOL.	PH	ACIDITY	HF	HT	SO4	N-NO3	N-NH4	CL	CA	MG	NA
SAMPLE SIZE :	2839.	2515.	1708.	2501.	1702.	2364.	2373.	2201.	2314.	1970.	1989.	1964.
MAXIMUM :	9335.	7.18	25.85	7.446	9.998	343.36	40.06	36.331	31.97	69.51	8.77	22.13
MINIMUM :	7.	3.36	1.09	0.000	0.026	0.18	0.02	0.002	0.006	0.010	0.003	0.015
RANGE :	9328.	3.82	24.76	7.446	9.971	343.18	40.03	36.329	31.97	69.50	8.77	22.11
ARITH. MEAN :	981.	++++	5.86	0.484	1.063	25.54	3.68	3.030	1.572	2.103	0.349	0.884
ARITH. STD. DEV :	1085.	++++	3.15	0.673	1.009	32.07	4.04	3.531	2.160	3.429	0.584	1.412
GEOM. MEAN :	563.	4.27	5.16	0.210	0.745	12.24	2.00	1.508	0.94	0.99	0.15	0.46
GEOM. STD. DEV. :	1.13	0.10	0.50	1.518	0.857	1.35	1.23	1.341	1.04	1.28	1.32	1.16
1ST QUARTILE :	260.	4.03	3.64	0.089	0.409	4.95	0.91	0.635	0.52	0.40	0.06	0.22
2ND QUARTILE :	617.	4.22	5.14	0.254	0.757	13.82	2.28	1.728	0.98	1.03	0.16	0.43
3RD QUARTILE :	1292.	4.48	7.17	0.607	1.384	33.13	5.04	4.196	1.85	2.59	0.41	1.01

***** : INSUFFICIENT DATA
++++ : NOT CALCULATED

TABLE 6

continued...

EVENT SAMPLING ANALYSIS RESULTS

SUDBURY ENVIROMENTAL STUDY

THE STATISTICAL TABLE - ALL DATA
(DEPOSITION)

ALL STATIONS
STATISTICAL PERIOD :780501-800531

		(MG/M**2)										
		K	SI	F	FE	CU	NI	PB	ZN	AL	CR	CO
SAMPLE SIZE	:	1985.	419.	2244.	2035.	2035.	2035.	2035.	2033.	2003.	2034.	2033.
MAXIMUM	:	13.30	6.10	8.62	41.490	12.622	12.325	2.614	5.100	46.078	0.3495	0.1914
MINIMUM	:	0.004	0.007	0.001	0.0009	0.0002	0.0001	0.0006	0.0010	0.0010	0.0001	0.0000
RANGE	:	13.29	6.09	8.62	41.489	12.621	12.325	2.614	5.099	46.077	0.3495	0.1914
ARITH. MEAN	:	0.54	0.49	0.21	0.606	0.163	0.084	0.116	0.122	0.362	0.0048	0.0037
ARITH. STD. DEV	:	0.95	0.64	0.34	1.674	0.607	0.423	0.155	0.283	1.219	0.0152	0.0097
GEOM. MEAN	:	0.24	0.29	0.11	0.231	0.026	0.012	0.067	0.056	0.114	0.0021	0.0014
GEOM. STD. DEV.	:	1.33	1.03	1.20	1.361	1.747	1.736	1.119	1.217	1.607	1.1149	1.3506
1ST QUARTILE	:	0.10	0.14	0.05	0.094	0.008	0.003	0.034	0.024	0.037	0.0009	0.0005
2ND QUARTILE	:	0.26	0.28	0.11	0.230	0.019	0.009	0.071	0.060	0.124	0.0020	0.0014
3RD QUARTILE	:	0.59	0.56	0.25	0.566	0.075	0.032	0.147	0.122	0.365	0.0039	0.0033

***** : INSUFFICIENT DATA
++++ : NOT CALCULATED

TABLE 7

CORRELATION COEFFICIENTS OF SES EVENT CONCENTRATION DATA

EVENT SAMPLING ANALYSIS RESULTS

LINEAR CORRELATION COEFFICIENT
99% CONFIDENCE LEVEL
(# OF OBSERVATION PTS)

PERIOD : JUN 6,78-MAY30,80

ALL STATIONS

	VOL	HF	H	SO4	NO3	NH4	CL	CA	MG	NA	K	SI	F	FE	CU	NI	PB	ZN	AL	CR	CD
VOL	1.000 2840																				
HF	-0.07 2501	1.000 2515																			
H	-0.10 1702	0.003 1708	1.000 1708																		
SO4	-0.12 2364	0.709 2363	0.026 1696	1.000 2372																	
NO3	-0.22 2373	0.608 2373	0.641 1697	0.487 2366	1.000 2382																
NH4	-0.16 2201	0.408 2201	0.563 1701	0.728 2164	0.557 2168	1.000 2209															
CL	-0.24 2314	0.074 2312	0.150 1687	0.133 2306	0.193 2316	0.101 2130	1.000 2322														
CA	-0.14 1970	0.252 1971	0.287 1657	0.504 1957	0.450 1963	0.496 1922	0.126 1943	1.000 1977													
MG	-0.14 1989	0.192 1988	0.235 1662	0.469 1977	0.400 1981	0.445 1928	0.114 1963	0.800 1952	1.000 1996												
NA	-0.18 1965				0.125 1959		0.926 1942		0.060 1926	1.000 1972											
K	-0.16 1985	0.086 1984	0.186 1658	0.295 1970	0.154 1977	0.338 1930	0.006 1956	0.366 1935	0.442 1946	0.074 1944	1.000 1992										
SI		0.166 419	0.141 382	0.241 413		0.224 415		0.316 393	0.297 393		0.227 388	1.000 420									
F	-0.10 2245	0.111 2245	0.092 1612	0.149 2238	0.141 2240	0.100 2062	0.113 2229				0.069 1890		1.000 2254								
FE	-0.13 2035		0.095 1620	0.247 1968	0.111 1970	0.202 1942	0.274 1955	0.136 1792	0.132 1804	0.244 1797		0.194 379	0.069 1880	1.000 2046							
CU	-0.11 2035		0.107 1620	0.287 1968		0.190 1942	0.343 1955			0.332 1797			0.088 1880	0.654 2046	1.000 2046						
NI	-0.09 2035		0.096 1620	0.283 1968		0.213 1942	0.286 1955		0.070 1804	0.265 1797			0.072 1880	0.776 2046	0.924 2046	1.000 2046					
PB	-0.17 2035	0.331 2004	0.347 1620	0.441 1968	0.339 1970	0.331 1942	0.328 1955	0.159 1792	0.152 1804	0.283 1797	0.093 1799	0.155 379	0.121 1880	0.558 2046	0.709 2046	0.685 2046	1.000 2046				
ZN	-0.09 2033	0.118 2000	0.109 1619	0.103 1967	0.173 1969	0.089 1941	0.124 1954					0.228 379		0.115 2042	0.076 2042	0.079 2042	0.126 2042	1.000 2042			
AL	-0.09 2003		0.078 1596	0.087 1937	0.203 1939	0.114 1913	0.115 1924	0.190 1767	0.144 1779	0.104 1772		0.241 356		0.578 2012	0.103 2012	0.104 2012	0.175 2012	0.075 2011	1.000 2012		
CR		0.105 2002	0.114 1619	0.073 1967	0.141 1969									0.235 2044	0.074 2044	0.105 2044	0.099 2044	0.437 2042	0.185 2012	1.000 2044	
CD	-0.14 2033	0.137 2000	0.169 1618	0.290 1966		0.177 1940	0.312 1953		0.079 1802	0.246 1795	0.080 1797	0.192 379	0.165 1878	0.525 2042	0.083 2042	0.656 2042	0.655 2042	0.156 2041	0.097 2011	0.086 2042	1.000 2042

TABLE 8

LINEAR REGRESSION COEFFICIENTS OF SES CONCENTRATION DATA

EVENT SAMPLING ANALYSIS RESULTS - SES

TWO VARIABLES OF THE LINEAR REGRESSION (A & B)

ALL STATIONS PERIOD : JUN 6.78-MAY31.80

	VOL	HF	HT	SO4	NO3	NH4	CL	CA	MG	NA	K	SI	F	FE	CU	NI	PB	ZN	AL	CR	CD
VOL	0.0																				
	1.000																				
HF		0.0																			
		1.000																			
HT		0.037	0.0																		
		1.131	1.000																		
SO4		0.828	-.597	0.0																	
		42.73	36.54	1.000																	
NO3		0.124	0.007	0.278	0.0																
		7.464	4.847	0.099	1.000																
NH4		0.174	0.014	0.060	0.214	0.0															
		4.025	3.612	0.105	0.381	1.000															
CL		0.336	0.142	0.268	0.263	0.290	0.0														
		1.048	0.096	0.030	0.219	0.152	1.000														
CA		0.177	0.100	0.073	0.111	0.112	0.272	0.0													
		1.697	1.501	0.059	0.304	0.412	0.073	1.000													
MG		0.032	0.018	0.008	0.016	0.017	0.047	0.002	0.0												
		0.274	0.235	0.011	0.058	0.075	0.015	0.161	1.000												
NA					0.114		-.018		0.149	0.0											
					0.085		0.595		0.339	1.000											
K		0.069	0.033	0.033	0.061	0.035	0.078	0.040	0.042	0.081	0.0										
		0.233	0.343	0.014	0.041	0.107	0.020	0.148	0.832	0.029	1.000										
SI		0.042	0.041	0.039		0.041		0.040	0.040		0.045	0.0									
		0.120	0.093	0.004		0.024		0.037	0.217		0.080	1.000									
F		0.420	0.007	0.017	0.021	0.021	0.029				0.027		0.0								
		0.211	0.174	0.005	0.021	0.026	0.015				0.052		1.000								
FE			0.055	0.035	0.076	0.055	0.071	0.075	0.080	0.075		0.027	0.100	0.0							
			0.308	0.018	0.042	0.098	0.093	0.088	0.435	0.145		0.425	0.137	1.000							
CU			0.007	-.013		0.010	0.011			0.014			0.033	-.006	0.0						
			0.151	0.013		0.052	0.070			0.117			0.105	0.394	1.000						
NI			0.004	-.005		0.003	0.007		0.013	0.009			0.015	-.004	0.002	0.0					
			0.071	0.006		0.027	0.026		0.061	0.041			0.042	0.197	0.409	1.000					
PB		0.007	0.002	0.004	0.009	0.009	0.014	0.014	0.015	0.015	0.016	0.011	0.018	0.012	0.014	0.014	0.0				
		0.163	0.124	0.004	0.014	0.020	0.012	0.011	0.055	0.018	0.017	0.035	0.029	0.068	0.142	0.311	1.000				
ZN		0.010	0.005	0.012	0.009	0.014	0.016					0.011		0.017	0.019	0.019	0.015	0.0			
		0.142	0.117	0.002	0.015	0.013	0.010					0.215		0.034	0.037	0.087	0.306	1.000			
AL			0.037	0.042	0.030	0.041	0.048	0.036	0.042	0.049		0.017		0.025	0.051	0.049	0.041	0.052	0.0		
			0.135	0.003	0.038	0.028	0.020	0.061	0.234	0.032		0.202		0.282	0.083	0.345	0.705	0.125	1.000		
CR															0.001	0.001	0.001			0.0	
															0.002	0.005	0.010			1.000	
CD									0.001		0.001		0.001					0.001	0.001	0.001	0.0
									0.002		0.001		0.002					0.004	0.002	0.058	1.000

TABLE 9: EVENT PRECIPITATION BACKGROUND CONTAMINANTS CONCENTRATION ASSOCIATED WITH WARM AND COLD FRONTAL PASSAGES

	MEAN BACKGROUND CONCENTRATION (MG/L)							
	WARM FRONT (A)			COLD FRONT (B)				
	MEAN	STDV	NN	MEAN	STDV	NN	B/A	T-T
HF	0.0883	0.0431	88.	0.0418	0.0283	96.	0.47	8.72*
PH +	4.05		88.	4.38		96.		
ACID	6.8417	2.5441	86.	3.8201	1.6817	83.	0.56	9.07*
SO4	4.4632	2.0465	89.	1.5748	1.1578	96.	0.35	11.92*
NNO3	0.8137	0.5212	89.	0.3569	0.3022	96.	0.44	7.36*
NNH4	0.5981	0.3796	88.	0.1995	0.1467	95.	0.33	9.50*
CL	0.2633	0.2046	89.	0.2249	0.3439	94.	0.85	0.91
CA	0.3606	0.2810	83.	0.1556	0.1559	91.	0.43	6.02*
MG	0.0578	0.0569	86.	0.0276	0.0333	91.	0.48	4.33*
NA	0.1222	0.1107	86.	0.1420	0.2364	90.	1.16	-0.71
K	0.0762	0.0759	86.	0.0519	0.0547	87.	0.68	2.41*
F	0.0387	0.0346	86.	0.0237	0.0355	94.	0.61	2.87*
FE	0.0599	0.0472	89.	0.0342	0.0418	94.	0.57	3.90*
CU	0.0028	0.0018	89.	0.0028	0.0039	94.	0.99	0.09
NI	0.0014	0.0015	89.	0.0014	0.0018	93.	1.06	-0.35
PB	0.0161	0.0099	88.	0.0079	0.0068	94.	0.49	6.51*
ZN	0.0156	0.0110	89.	0.0091	0.0071	93.	0.58	4.76*
AL	0.0506	0.0534	89.	0.0235	0.0357	88.	0.46	3.97*
CR	0.0004	0.0002	89.	0.0004	0.0002	91.	0.95	0.64
CD	0.0004	0.0005	89.	0.0003	0.0004	92.	0.78	1.22

+ : IN PH UNITS
MEAN : MEAN CONCENTRATION OF DAILY AREA MEANS
STDV : STANDARD DEVIATION
NN : NUMBER OF DATA POINTS
T-T : STUDENT-T STATISTICS
* : STATISTICALLY SIGNIFICANT AT 95 % CONFIDENCE LEVEL

TABLE 10: EVENT PRECIPITATION BACKGROUND CONTAMINANTS CONCENTRATION ASSOCIATED WITH SUMMER AND WINTER SEASONS

	MEAN BACKGROUND CONCENTRATION (MG/L)							
	SUMMER (A)			WINTER (B)				
	MEAN	STDV	NN	MEAN	STDV	NN	A/B	T-T
HF	0.0659	0.0455	93.	0.0622	0.0403	91.	1.06	0.59
PH +	4.18		93.	4.21		91.		
ACID	5.5207	2.7745	91.	5.1675	2.4696	78.	1.07	0.87
SO4	3.4896	2.4469	94.	2.4218	1.7374	91.	1.44	3.41*
NNO3	0.4908	0.3572	94.	0.6654	0.5670	91.	0.74	-2.51*
NNH4	0.4316	0.3229	93.	0.3494	0.3659	90.	1.24	1.61
CL	0.1650	0.1099	92.	0.3231	0.3728	91.	0.51	-3.90*
CA	0.3267	0.2659	90.	0.1748	0.1960	84.	1.87	4.27*
MG	0.0566	0.0552	93.	0.0264	0.0337	84.	2.15	4.35*
NA	0.0824	0.0667	93.	0.1883	0.2502	83.	0.44	-3.93*
K	0.0801	0.0708	93.	0.0453	0.0573	80.	1.77	3.52*
F	0.0281	0.0160	90.	0.0337	0.0480	90.	0.83	-1.04
FE	0.0452	0.0452	93.	0.0482	0.0475	90.	0.94	-0.45
CU	0.0025	0.0021	93.	0.0031	0.0038	90.	0.79	-1.41
NI	0.0012	0.0014	93.	0.0016	0.0018	89.	0.75	-1.63
PB	0.0107	0.0072	92.	0.0130	0.0111	90.	0.82	-1.70
ZN	0.0125	0.0103	93.	0.0120	0.0093	89.	1.05	0.39
AL	0.0304	0.0325	93.	0.0445	0.0590	84.	0.68	-2.00*
CR	0.0004	0.0002	92.	0.0003	0.0001	88.	1.22	2.38*
CD	0.0002	0.0003	92.	0.0004	0.0006	89.	0.56	-2.82*

+ : IN PH UNITS
MEAN : MEAN CONCENTRATION OF DAILY AREA MEANS
STDV : STANDARD DEVIATION
NN : NUMBER OF DATA POINTS
T-T : STUDENT-T STATISTICS
* : STATISTICALLY SIGNIFICANT AT 95 % CONFIDENCE LEVEL

Table 11: Sector Mean Concentrations Based on a 24-Hour Backward Air Parcel Trajectory Classification

MEAN BACKGROUND CONCENTRATION (MG/L)

	N SECTOR 24HR			NE SECTOR 24HR			E SECTOR 24HR			SE SECTOR 24HR		
	MEAN	STDV	NN	MEAN	STDV	NN	MEAN	STDV	NN	MEAN	STDV	NN
HF	0.0363	0.0233	9.	0.0689	0.0475	13.	0.0555	0.0267	19.	0.0793	0.0526	22.
PH *	4.44		9.	4.16		13.	4.26		19.	4.10		22.
ACID	4.0196	1.2605	6.	5.6527	3.5700	11.	5.1872	1.9088	15.	6.1036	3.1470	22.
SO4	1.3586	1.7185	9.	3.5163	3.2614	13.	2.5398	1.3616	19.	3.5779	2.8452	22.
NNO3	0.4280	0.3203	9.	0.4052	0.3076	13.	0.4511	0.3678	19.	0.5730	0.4183	22.
NNH4	0.2004	0.3731	8.	0.2916	0.3136	13.	0.2123	0.1376	18.	0.4372	0.5128	22.
CL	0.4757	0.8230	9.	0.1647	0.1305	13.	0.2167	0.2231	19.	0.2566	0.2423	22.
CA	0.1819	0.2081	8.	0.2283	0.1976	13.	0.1712	0.1539	17.	0.2069	0.2261	22.
MG	0.0382	0.0330	8.	0.0292	0.0377	13.	0.0237	0.0249	17.	0.0372	0.0482	22.
NA	0.3267	0.5110	8.	0.0752	0.0831	12.	0.1556	0.3163	17.	0.1414	0.1409	22.
K	0.0514	0.0343	8.	0.0416	0.0381	12.	0.0290	0.0218	17.	0.0509	0.0490	22.
F	0.0159	0.0134	8.	0.0278	0.0227	13.	0.0252	0.0211	18.	0.0248	0.0183	22.
FE	0.0505	0.0498	9.	0.0521	0.0449	13.	0.0463	0.0515	19.	0.0379	0.0396	22.
CU	0.0027	0.0020	9.	0.0042	0.0046	13.	0.0034	0.0074	19.	0.0023	0.0016	22.
NI	0.0017	0.0012	9.	0.0022	0.0032	13.	0.0016	0.0024	18.	0.0011	0.0006	22.
PB	0.0066	0.0038	9.	0.0167	0.0146	13.	0.0092	0.0052	19.	0.0139	0.0118	22.
ZN	0.0105	0.0081	9.	0.0116	0.0077	13.	0.0097	0.0082	19.	0.0113	0.0083	22.
AL	0.0322	0.0318	8.	0.0362	0.0326	13.	0.0355	0.0433	19.	0.0295	0.0344	20.
CR	0.0004	0.0002	8.	0.0003	0.0001	13.	0.0003	0.0001	19.	0.0003	0.0001	22.
CD	0.0001	0.0001	9.	0.0009	0.0007	13.	0.0004	0.0006	19.	0.0006	0.0007	22.

	S SECTOR 24HR			SW SECTOR 24HR			W SECTOR 24HR			NW SECTOR 24HR		
	MEAN	STDV	NN	MEAN	STDV	NN	MEAN	STDV	NN	MEAN	STDV	NN
HF	0.0760	0.0444	46.	0.0637	0.0432	52.	0.0402	0.0218	14.	0.0481	0.0479	4.
PH *	4.12		46.	4.19		52.	4.40		14.	4.32		4.
ACID	5.9590	2.5639	46.	5.2545	2.6006	49.	3.7781	1.4668	11.	3.9088	1.9129	4.
SO4	3.4145	2.2096	46.	3.0743	1.9519	53.	1.9508	1.1151	14.	1.5792	1.3179	4.
NNO3	0.6731	0.5515	46.	0.6702	0.5299	53.	0.5363	0.4628	14.	0.1824	0.1398	4.
NNH4	0.4299	0.3542	46.	0.4582	0.3063	53.	0.3942	0.3566	14.	0.1737	0.1142	4.
CL	0.2363	0.2600	45.	0.2184	0.1446	53.	0.2756	0.3116	13.	0.1226	0.0554	4.
CA	0.2323	0.2607	46.	0.3604	0.2777	47.	0.2646	0.2439	13.	0.1650	0.0521	4.
MG	0.0322	0.0327	46.	0.0642	0.0667	50.	0.0423	0.0423	13.	0.0319	0.0036	4.
NA	0.1127	0.1238	45.	0.1073	0.0809	51.	0.1593	0.1344	13.	0.0661	0.0268	4.
K	0.0648	0.0695	45.	0.0817	0.0746	49.	0.0709	0.0566	12.	0.0538	0.0182	4.
F	0.0331	0.0446	45.	0.0315	0.0211	52.	0.0296	0.0168	13.	0.0327	0.0196	4.
FE	0.0439	0.0532	46.	0.0540	0.0469	52.	0.0442	0.0350	13.	0.0340	0.0204	4.
CU	0.0023	0.0019	46.	0.0027	0.0015	52.	0.0032	0.0021	13.	0.0022	0.0017	4.
NI	0.0012	0.0017	46.	0.0014	0.0011	52.	0.0017	0.0016	13.	0.0010	0.0003	4.
PB	0.0127	0.0109	46.	0.0117	0.0075	51.	0.0110	0.0047	13.	0.0053	0.0034	4.
ZN	0.0123	0.0094	46.	0.0141	0.0114	52.	0.0126	0.0138	12.	0.0121	0.0072	4.
AL	0.0261	0.0247	45.	0.0537	0.0690	52.	0.0394	0.0436	13.	0.0123	0.0063	4.
CR	0.0004	0.0002	46.	0.0004	0.0002	51.	0.0004	0.0002	12.	0.0007	0.0006	4.
CU	0.0002	0.0002	45.	0.0043	0.0003	52.	0.0004	0.0005	12.	0.0001	0.0001	4.

* : IN PH UNITS
MEAN : MEAN CONCENTRATION OF DAILY AREA MEANS
STDV : STANDARD DEVIATION
NN : NUMBER OF DATA POINTS

Table 12. Sector Mean Concentrations Based on a 48-Hour Backward Air Parcel Trajectory Classification

MEAN BACKGROUND CONCENTRATION (MG/L)

	N SECTOR 48HR			NE SECTOR 48HR			E SECTOR 48HR			SE SECTOR 48HR		
	MEAN	STDV	NN	MEAN	STDV	NN	MEAN	STDV	NN	MEAN	STDV	NN
HF	0.0437	0.0304	16.	0.0658	0.0466	17.	0.0838	0.0595	15.	0.0823	0.0467	11.
PH *	4.36		16.	4.18		17.	4.08		15.	4.08		11.
ACID	4.0818	1.8021	15.	5.6180	3.2672	14.	6.6701	3.1691	13.	6.0039	2.9046	10.
SO4	1.8204	1.6321	16.	2.9849	3.0194	17.	3.8775	2.6378	15.	3.0369	1.7603	11.
NNO3	0.3712	0.3073	16.	0.3976	0.2902	17.	0.6154	0.5405	15.	0.6943	0.8017	11.
NNH4	0.2684	0.3030	15.	0.2389	0.2562	17.	0.3674	0.3344	14.	0.3563	0.3542	11.
CL	0.3278	0.6322	16.	0.1884	0.1330	17.	0.3022	0.2859	15.	0.3031	0.4293	11.
CA	0.1852	0.1821	16.	0.2194	0.1735	17.	0.2912	0.3760	14.	0.2066	0.1682	11.
MG	0.0357	0.0313	16.	0.0287	0.0352	17.	0.0488	0.0763	14.	0.0332	0.0270	11.
NA	0.2074	0.3747	16.	0.0779	0.0721	17.	0.2053	0.3487	14.	0.1848	0.2096	10.
K	0.0461	0.0307	16.	0.0386	0.0349	17.	0.0651	0.0955	14.	0.0471	0.0351	10.
F	0.0196	0.0166	16.	0.0287	0.0222	16.	0.0302	0.0230	15.	0.0310	0.0261	11.
FE	0.0495	0.0578	16.	0.0506	0.0477	17.	0.0485	0.0359	15.	0.0283	0.0324	11.
CU	0.0024	0.0022	16.	0.0053	0.0084	17.	0.0027	0.0017	15.	0.0021	0.0021	11.
NI	0.0015	0.0010	15.	0.0023	0.0036	17.	0.0014	0.0009	15.	0.0010	0.0008	11.
PB	0.0073	0.0049	16.	0.0118	0.0110	17.	0.0171	0.0156	15.	0.0174	0.0194	11.
ZN	0.0089	0.0059	16.	0.0105	0.0070	17.	0.0147	0.0153	15.	0.0136	0.0143	11.
AL	0.0401	0.0466	14.	0.0323	0.0381	17.	0.0351	0.0270	15.	0.0201	0.0233	11.
CR	0.0003	0.0002	15.	0.0003	0.0001	17.	0.0004	0.0001	15.	0.0003	0.0001	11.
CD	0.0002	0.0002	16.	0.0006	0.0006	17.	0.0006	0.0008	15.	0.0007	0.0007	11.

	S SECTOR 48HR			SW SECTOR 48HR			W SECTOR 48HR			NW SECTOR 48HR		
	MEAN	STDV	NN	MEAN	STDV	NN	MEAN	STDV	NN	MEAN	STDV	NN
HF	0.0807	0.0464	36.	0.0622	0.0385	52.	0.0467	0.0278	17.	0.0444	0.0237	15.
PH *	4.09		36.	4.20		52.	4.33		17.	4.35		15.
ACID	6.2767	2.6404	35.	5.3926	2.5190	48.	4.9317	2.2092	14.	3.5309	1.0521	15.
SO4	3.7919	2.4146	36.	3.1003	1.9993	52.	2.3179	1.6003	17.	1.8737	1.0446	16.
NNO3	0.6275	0.4297	36.	0.7050	0.5354	52.	0.5055	0.3410	17.	0.4753	0.4318	16.
NNH4	0.4637	0.3348	36.	0.4845	0.4138	52.	0.3254	0.2323	17.	0.3239	0.3236	16.
CL	0.1915	0.1176	35.	0.2490	0.2033	52.	0.2238	0.2528	16.	0.1829	0.1748	16.
CA	0.2286	0.2499	35.	0.3034	0.2706	47.	0.3338	0.2681	16.	0.2113	0.1462	14.
MG	0.0357	0.0429	35.	0.0490	0.0493	49.	0.0565	0.0584	16.	0.0479	0.0615	15.
NA	0.0831	0.0490	34.	0.1304	0.1165	50.	0.1086	0.0928	16.	0.1134	0.1170	15.
K	0.0609	0.0470	34.	0.0785	0.0806	49.	0.0760	0.0629	15.	0.0479	0.0242	14.
F	0.0355	0.0485	35.	0.0301	0.0212	52.	0.0264	0.0180	15.	0.0240	0.0155	15.
FE	0.0405	0.0499	36.	0.0526	0.0535	51.	0.0530	0.0413	16.	0.0442	0.0231	16.
CU	0.0023	0.0013	36.	0.0027	0.0018	51.	0.0024	0.0014	16.	0.0028	0.0019	16.
NI	0.0011	0.0012	36.	0.0014	0.0017	51.	0.0011	0.0006	16.	0.0016	0.0014	16.
PB	0.0129	0.0085	36.	0.0112	0.0057	50.	0.0113	0.0062	16.	0.0081	0.0047	16.
ZN	0.0119	0.0087	36.	0.0124	0.0064	51.	0.0152	0.0174	16.	0.0121	0.0079	15.
AL	0.0274	0.0245	36.	0.0512	0.0717	49.	0.0448	0.0454	16.	0.0284	0.0230	16.
CR	0.0004	0.0002	36.	0.0004	0.0002	51.	0.0005	0.0002	15.	0.0005	0.0003	15.
CD	0.0002	0.0001	35.	0.0003	0.0005	51.	0.0003	0.0004	16.	0.0001	0.0001	15.

* : IN PH UNITS
MEAN : MEAN CONCENTRATION OF DAILY AREA MEANS
STDV : STANDARD DEVIATION
NN : NUMBER OF DATA POINTS

Table 13: Comparison of Inco Plume Sector and Background Precipitation Concentrations.

INCO CONTRIBUTION <ALL>

PARA	BK MN (A)	PM MN (B)	BK SD	PM SD	RATIO (B/A)	NN	T-T
HF	0,06032	0,07847	0.04109	0,05184	1,30087	113	6,27290
PH	4.22	4.11	-	-	-	113	-
ACID	5,29364	6,59712	2,49608	3,08509	1,24624	94	7,03630
SO4	2,98607	5,04205	2,20619	2,85790	1,68853	115	13,53223
NNO3	0,58238	0,64339	0,48000	0,54328	1,10477	115	3,46611
NNH4	0,34398	0,58319	0,32229	0,37292	1,68025	113	6,96337
CL	0,22432	0,45314	0.21495	0,65547	2,02011	114	4,31988
CA	0.24179	0,29686	0,23806	0,29168	1,22777	106	3,47836
MG	0,04060	0,05343	0.04883	0,05617	1,31614	109	3,44715
NA	0,10814	0,18846	0,15809	0,32117	1,74274	109	3,81732
K	0,05502	0,07342	0,06143	0,06773	1,33446	106	3,31672
F	0,02549	0,04312	0,01877	0,04168	1,69140	113	5,63667
FE	0,05187	0,18996	0,04904	0,20789	3,66197	113	7,51954
CU	0,00324	0,11106	0,00362	0,19318	34,23209	113	5,96272
NI	0,00164	0,05015	0,00191	0,08299	30,64052	113	6,23876
PB	0,01154	0,02783	0,00957	0,02820	2,41206	112	7,60424
ZN	0,01018	0,01962	0,00788	0,01886	1,92789	112	5,93876
AL	0,04394	0,07209	0,05431	0,11099	1,64055	112	3,60335
CR	0,00038	0.00075	0,00022	0,00106	1,97062	110	3,91621
CD	0.00026	0,00119	0,00035	0,00129	4.54638	111	8,12341

XX(J) , YY(J) ! PAIR OF BACKGROUND & PLUME CON
NN ! NUMBER OF PAIRS
BK MN ! BACKGROUND MEAN (SUM XX(J))/NN
PM MN ! PLUME MEAN (SUM YY(J))/NN
BK SD ! BACKGROUND STANDARD DEVIATION
PM SD ! PLUME STANDARD DEVIATION
RATIO ! (PM MN)/(BK MN)
T-T ! PAIRED T TEST VALUE

Table 14: Comparison of Falconbridge Plume Sector and Background Precipitation Concentrations

FALCONBRIDGE CONTRIBUTION <ALL>

PARA	BK MN (A)	PM MN (B)	BK SD	PM SD	RATIO (B/A)	NN	T-T
HF	0,05334	0.07065	0,03610	0,04345	1,32449	85	6,33910
PH	4.27	4.15	-	-	-	85	-
ACID	4,76437	5,83179	2,43392	2,98414	1,22404	67	5,21164
SO4	2,44310	3,48956	2,01688	2,42582	1,42833	86	7.65606
NNO3	0,44687	0,56536	0,42189	0,62893	1,26515	86	3.39246
NNH4	0,28070	0,36845	0,23313	0,33377	1,31260	83	3,24683
CL	0,20887	0,28560	0,30434	0,30391	1,36736	85	2,03608
CA	0,19205	0,24470	0,18237	0,29260	1,27414	79	2,09224
MG	0,02946	0,03703	0,02993	0,04407	1,25699	79	1,94279
NA	0,12848	0,13225	0.23466	0,15321	1,02931	76	0,14718
K	0,04716	0,05907	0,04122	0,05349	1,25253	75	2,13802
F	0.02165	0,02899	0,01619	0,02671	1,33916	81	3.15659
FE	0,04261	0,09873	0,04958	0,16348	2.31723	82	3.23354
CU	0.00298	0,01709	0.00416	0,03026	5,72827	82	4,50343
NI	0,00145	0,00643	0,00188	0,00902	4,43212	81	5.30034
PB	0,01018	0,01638	0.00776	0,01340	1,60888	83	5,37063
ZN	0,00980	0,01754	0.00735	0,02474	1,82741	82	2.87815
AL	0.03010	0,06651	0,04111	0,13460	2,20967	79	2,49832
CR	0.00032	0,00057	0,00013	0,00064	1,78156	82	3.60199
CD	0,00036	0,00057	0,00050	0.00052	1,56725	82	4,52449

XX(J) , YY(J) : PAIR OF BACKGROUND & PLUME CON
NN : NUMBER OF PAIRS
BK MN : BACKGROUND MEAN (SUM XX(J))/NN
PM MN : PLUME MEAN (SUM YY(J))/NN
BK SD : BACKGROUND STANDARD DEVIATION
PM SD : PLUME STANDARD DEVIATION
RATIO : (PM MN)/(BK MN)
T-T : PAIRED T TEST VALUE

TABLE 15: MEAN ADDITIONAL CONCENTRATION (MG/L) DUE TO INCO AS A FUNCTION OF DISTANCE FROM THE SOURCE

	(3.- 6.) KM			(9.-11.) KM			(14.-16.) KM			(17.-24.) KM			(27.-32.) KM			(35.-50.) KM		
PM	NN	CONC	STDV	NN	CONC	STDV	NN	CONC	STDV	NN	CONC	STDV	NN	CONC	STDV	NN	CONC	STDV
HF	173	0.0172	0.0392	71	0.0162	0.0309	29	0.0117	0.0276	70	0.0145	0.0353	55	0.0208	0.0407	5	0.0433	0.0341
PH	173	4.76	-	71	4.79	-	29	4.93	-	70	4.84	-	55	4.68	-	5	4.36	-
ACID	134	1.1304	1.4272	57	1.1727	1.5780	26	1.0330	2.2436	56	1.1068	2.2272	47	0.9304	2.9199	3	1.6531	1.1962
SO4	176	2.1810	2.3127	70	1.8980	1.7661	29	1.1850	1.3317	71	1.6655	1.9870	54	1.4989	2.4741	5	1.5700	1.9006
NNO3	178	0.0561	0.2701	70	0.0761	0.2376	29	0.0021	0.2503	71	0.0646	0.3268	56	0.0694	0.3553	5	0.2292	0.4000
NNH4	170	0.2640	0.4681	67	0.2192	0.3742	29	0.0779	0.2646	70	0.1709	0.3573	55	0.0229	0.2680	4	0.2118	0.3428
CL	174	0.1425	0.5250	69	0.1271	0.5446	29	0.0234	0.1961	69	0.4020	1.3439	56	0.0567	0.2070	5	0.1360	0.1962
CA	158	0.0625	0.2055	63	0.0485	0.2164	28	0.0899	0.2400	62	0.0488	0.1792	46	0.0193	0.1408	4	0.1092	0.3541
MG	164	0.0178	0.0566	62	0.0149	0.0690	28	0.0062	0.0320	63	0.0097	0.0258	50	0.0037	0.0498	4	0.0348	0.0659
NA	159	0.1000	0.3001	63	0.0374	0.1399	28	0.0115	0.0688	62	0.0881	0.4594	51	0.0233	0.1037	5	0.0352	0.0539
K	154	0.0095	0.0586	62	0.0323	0.1034	28	0.0018	0.0451	65	0.0315	0.1081	49	0.0235	0.1340	5	0.0174	0.0757
F	174	0.0205	0.0354	68	0.0088	0.0203	27	0.0050	0.0204	69	0.0096	0.0314	54	0.0122	0.0346	5	0.0076	0.0168
FE	166	0.1953	0.2755	68	0.1059	0.2280	28	0.1528	0.2079	73	0.1111	0.2364	54	0.0224	0.0571	5	0.0086	0.0165
CU	168	0.1552	0.2756	68	0.0574	0.0916	28	0.0735	0.0869	73	0.0698	0.1259	54	0.0171	0.0331	5	0.0051	0.0038
NI	168	0.0691	0.1059	68	0.0333	0.0714	28	0.0313	0.0314	73	0.0331	0.0703	54	0.0072	0.0144	5	0.0010	0.0010
PB	168	0.0206	0.0297	68	0.0102	0.0176	28	0.0157	0.0159	73	0.0157	0.0232	53	0.0056	0.0137	4	0.0069	0.0073
ZN	167	0.0120	0.0223	68	0.0075	0.0150	28	0.0070	0.0136	73	0.0092	0.0309	52	0.0112	0.0299	5	0.0034	0.0095
AL	167	0.0294	0.0764	68	0.0224	0.0731	28	0.0585	0.1917	72	0.0280	0.1019	53	0.0009	0.0407	5	0.0065	0.0174
CR	164	0.0006	0.0021	66	0.0003	0.0009	27	0.0001	0.0004	71	0.0001	0.0004	49	0.0004	0.0016	5	0.0001	0.0001
CD	167	0.0012	0.0021	68	0.0005	0.0012	28	0.0007	0.0010	72	0.0010	0.0020	52	0.0005	0.0009	5	0.0001	0.0001

NN = Number of Data Points
CONC = Mean Concentration
STDV = Standard Deviation

TABLE 16: MEAN ADDITIONAL CONCENTRATION DUE TO FALCONBRIDGE AS A FUNCTION OF DISTANCE FROM THE SOURCE

	(6.-11.) KM			(17.-19.) KM			(21.-24.) KM		
PH	NN	CONC	STDV	NN	CONC	STDV	NN	CONC	STDV
HF	47	0.0148	0.0326	35	0.0251	0.0366	78	0.0176	0.0349
PH	47	4.83	-	35	4.60	-	78	4.75	-
ACID	38	1.2588	2.3575	31	1.1293	1.8154	61	1.0063	2.3591
SO4	47	1.1277	1.5071	37	1.0119	1.9608	79	1.1296	1.6574
NNO3	47	0.1577	0.4253	36	0.1685	0.5333	79	0.1253	0.3836
NNH4	47	0.0787	0.2103	36	0.0674	0.3384	76	0.1376	0.3111
CL	47	0.1225	0.3461	35	0.0501	0.1413	77	0.0802	0.3096
CA	45	0.1009	0.2958	34	0.0382	0.1884	68	0.0139	0.2201
MG	45	0.0194	0.0552	34	-0.0006	0.0309	68	0.0051	0.0255
NA	43	0.0317	0.2130	32	0.0169	0.0772	68	0.0479	0.2913
K	41	0.0094	0.0375	31	0.0043	0.0415	65	0.0124	0.0628
F	45	0.0074	0.0251	35	0.0117	0.0235	73	0.0045	0.0175
FE	46	0.0885	0.1863	35	0.0372	0.1016	73	0.0357	0.1726
CU	47	0.0228	0.0394	36	0.0069	0.0144	73	0.0128	0.0274
NI	47	0.0089	0.0140	35	0.0028	0.0057	72	0.0040	0.0093
PB	47	0.0097	0.0158	34	0.0109	0.0150	74	0.0045	0.0107
ZN	46	0.0166	0.0576	35	0.0079	0.0169	72	0.0050	0.0172
AL	47	0.0732	0.1757	35	0.0226	0.0524	72	0.0141	0.0435
CR	45	0.0004	0.0008	35	0.0002	0.0005	73	0.0002	0.0008
CD	46	0.0003	0.0006	35	0.0002	0.0003	72	0.0002	0.0005

	(28.-33.) KM			(38.-41.) KM			(50.-50.) KM		
PH	NN	CONC	STDV	NN	CONC	STDV	NN	CONC	STDV
HF	21	0.0144	0.0335	22	0.0293	0.0275	6	0.0191	0.0203
PH	21	4.04	-	22	4.53	-	0	-	
ACID	19	0.6859	1.8626	16	1.8354	1.4153	5	1.1930	1.5446
SO4	21	0.9733	1.7815	22	1.5998	1.4469	6	0.7525	0.4910
NNO3	21	0.1019	0.2370	22	0.1464	0.1893	6	0.0967	0.1073
NNH4	20	0.0951	0.2527	22	0.1532	0.2180	6	0.0365	0.1198
CL	21	-0.0873	0.4678	22	0.1092	0.1891	6	0.2217	0.3084
CA	18	0.0264	0.1506	19	0.0412	0.2516	5	-0.0340	0.2160
MG	18	0.0054	0.0280	19	0.0114	0.0410	5	-0.0015	0.0263
NA	18	-0.0916	0.2811	20	0.0269	0.0906	5	0.1180	0.2048
K	18	0.0062	0.0201	20	0.0159	0.0684	5	0.0225	0.0166
F	19	0.0151	0.0209	19	0.0016	0.0156	4	0.0025	0.0104
FE	20	-0.0025	0.0362	18	-0.0021	0.1104	6	0.0271	0.0400
CU	19	0.0071	0.0216	19	0.0011	0.0025	6	0.0037	0.0036
NI	19	0.0048	0.0141	19	-0.0000	0.0013	5	-0.0001	0.0003
PB	20	0.0036	0.0045	19	0.0069	0.0098	6	0.0058	0.0121
ZN	20	-0.0005	0.0067	19	0.0024	0.0119	6	0.0242	0.0305
AL	17	-0.0135	0.0425	18	0.0149	0.0588	5	0.0054	0.0129
CR	20	0.0000	0.0003	19	0.0001	0.0003	6	0.0001	0.0003
CD	20	0.0001	0.0004	19	0.0001	0.0002	6	0.0005	0.0005

NN = Number of Data Points
CONC = Mean Concentration
STDV = Standard Deviation

TABLE 17: DEPENDENCE OF INCO ADDITIONAL CONCENTRATION ON DISTANCE FROM SOURCE USING INDIVIDUAL DATA POINTS

CONC = A1 + B1 * R (1)
CONC = A2 + B2 / R (2)
LN(CONC) = A3 + B3 * R (3)
LN(R * CONC) = A4 + B4 * R (4)

	CORRELATION COEFFICIENT				REGRESSION COEFFICIENT							
PARAMETER	COR1	COR2	COR3	COR4	A1	B1	A2	B2	A3	B3	A4	B4
HF	0.04	0.00	0.06	0.45	0.01516	0.00014	0.01681	0.00138	-5.08353	0.00957	-3.78185	0.08498
ACID	-0.02	-0.01	-0.04	0.35	1.17559	-0.00457	1.14997	-0.26225	-0.71137	-0.00709	0.58748	0.06899
SO4	-0.13	0.11	-0.17	0.24	2.23047	-0.02802	1.54563	2.40978	0.15978	-0.03079	1.45542	0.04509
NNO3	0.03	0.02	0.05	0.42	0.04876	0.00096	0.05222	0.06569	-3.83281	0.00992	-2.53710	0.08561
NNH4	-0.17	0.13	-0.12	0.21	0.28498	-0.00719	0.11640	0.56415	-2.67763	-0.02648	-1.38094	0.04941
CL	-0.04	-0.00	-0.05	0.38	0.22295	-0.00291	0.18791	-0.01832	-2.81840	-0.00752	-1.52057	0.06806
CA	-0.05	0.07	0.01	0.38	0.06943	-0.00115	0.03365	0.15506	-3.67031	0.00133	-2.37744	0.07730
MG	-0.07	0.08	0.00	0.26	0.01843	-0.00040	0.00736	0.04379	-4.72948	0.00002	-3.43959	0.07618
NA	-0.09	0.06	-0.08	0.26	0.10471	-0.00255	0.04614	0.18903	-3.64797	-0.01638	-2.34868	0.05898
K	0.07	-0.07	0.01	0.37	0.01047	0.00062	0.02789	-0.07051	-4.28762	0.00270	-2.98351	0.07812
F	-0.10	0.13	0.01	0.31	0.01851	-0.00033	0.00827	0.04394	-4.49483	0.00274	-3.20218	0.07854
FE	-0.23	0.18	-0.32	0.00	0.21056	-0.00576	0.07254	0.47068	-2.58071	-0.07457	-1.27931	0.00093
CU	-0.24	0.24	-0.43	-0.02	0.16095	-0.00497	0.02717	0.51710	-2.58605	-0.07875	-1.28540	-0.00322
NI	-0.25	0.21	-0.46	-0.06	0.07275	-0.00218	0.01929	0.18784	-3.26306	-0.08644	-1.96243	-0.01091
PB	-0.18	0.16	-0.16	0.24	0.02148	-0.00047	0.00987	0.04119	-4.82873	-0.03034	-3.53212	0.04563
ZN	-0.03	0.05	-0.05	0.33	0.01113	-0.00008	0.00855	0.01192	-5.47644	-0.00981	-4.17696	0.06591
AL	-0.08	0.05	-0.02	0.29	0.03531	-0.00073	0.01956	0.04706	-4.72417	-0.00444	-3.42404	0.07109
CR	-0.08	0.09	-0.09	0.63	0.00054	-0.00001	0.00018	0.00146	-7.91928	-0.00771	-6.61833	0.06795
CD	-0.13	0.13	-0.14	0.18	0.00125	-0.00002	0.00061	0.00241	-7.82653	-0.03304	-6.52487	0.04255

TABLE 18: DEPENDENCE OF INCO ADDITIONAL CONCENTRATION ON DISTANCE FROM SOURCE USING GROUPED DATA POINTS

CONC = A1 + B1 * R (1)
CONC = A2 + B2 / R (2)
LN(CONC) = A3 + B3 * R (3)
LN(R * CONC) = A4 + B4 * R (4)

PARAMETER	CORRELATION COEFFICIENT COR1	COR2	COR3	COR4	REGRESSION COEFFICIENT A1	B1	A2	B2	A3	B3	A4	B4
HF	0.79	-0.39	0.77	0.99	0.00653	0.00070	0.02606	-0.06869	-4.51678	0.02688	-2.84029	0.08227
ACID	0.52	-0.23	0.45	0.97	0.98397	0.01002	1.25461	-0.88687	0.01768	0.00675	1.69418	0.06214
SO4	-0.50	0.77	-0.43	0.97	1.93068	-0.01321	1.34354	4.07821	0.63118	-0.00692	2.30768	0.04847
NNO3	0.74	-0.37	0.42	0.72	-0.00330	0.00431	0.11728	-0.43390	-4.10876	0.05132	-2.43226	0.10671
NNH4	-0.35	0.60	-0.34	0.45	0.21000	-0.00244	0.09356	0.85346	-1.59135	-0.02456	0.08515	0.03083
CL	-0.11	0.09	-0.07	0.57	0.17958	-0.00116	0.14154	0.18646	-2.10126	-0.00528	-0.42475	0.05011
CA	0.24	-0.08	0.00	0.78	0.05115	0.00059	0.06598	-0.03737	-2.90141	0.00016	-1.22490	0.05555
MG	0.39	0.01	0.09	0.77	0.00775	0.00034	0.01435	0.00205	-4.60022	0.00577	-2.92373	0.06116
NA	-0.44	0.64	-0.29	0.56	0.07575	-0.00128	0.02057	0.37484	-2.88727	-0.01841	-1.21077	0.03698
K	0.15	-0.25	0.21	0.79	0.01580	0.00015	0.02284	-0.05170	-6.15727	0.05074	-2.51682	0.06549
F	-0.41	0.77	-0.31	0.86	0.01404	-0.00017	0.00558	0.06366	-4.41946	-0.01108	-2.74297	0.04432
FE	-0.42	0.81	-0.95	-0.63	0.20186	-0.00513	0.02738	0.90914	-0.94456	-0.09036	0.73194	-0.03497
CU	-0.86	0.92	-0.95	-0.67	0.13355	-0.00353	0.00313	0.75641	-1.41698	-0.09039	0.25952	-0.03500
NI	-0.91	0.93	-0.95	-0.76	0.06294	-0.00169	0.00170	0.34688	-1.85801	-0.11404	-0.18151	-0.05865
PB	-0.78	0.75	-0.79	0.64	0.01941	-0.00035	0.00713	0.06716	-3.86439	-0.03127	-2.18789	0.02412
ZN	-0.54	0.54	-0.62	0.69	0.01100	-0.00013	0.00631	0.02629	-4.41507	-0.02212	-2.73858	0.03327
AL	-0.62	0.31	-0.67	-0.24	0.04355	-0.00096	0.01649	0.09842	-2.74751	-0.07788	-1.07101	-0.02249
CR	-0.53	0.30	-0.46	0.46	0.00042	-0.00001	0.00006	0.00247	-7.96881	-0.02960	-6.29237	0.02579
CD	-0.78	0.71	-0.82	-0.06	0.00117	-0.00002	0.00034	0.00444	-6.36236	-0.05863	-4.68586	-0.00324

TABLE 19: DEPENDENCE OF FALCONBRIDGE ADDITIONAL CONCENTRATION ON DISTANCE FROM SOURCE USING INDIVIDUAL DATA POINTS

CONC = A1 + B1 * R (1)
CONC = A2 + B2 / R (2)
LN(CONC) = A3 + B3 * R (3)
LN(R * CONC) = A4 + B4 * R (4)

PARAMETER	CORRELATION COEFFICIENT COR1	COR2	COR3	COR4	REGRESSION COEFFICIENT A1	B1	A2	B2	A3	B3	A4	B4
HF	0.07	-0.06	0.12	0.40	0.01437	0.00022	0.02235	-0.05369	-5.16594	0.01887	-3.25690	0.06729
ACID	0.02	-0.01	0.03	0.29	1.05477	0.00358	1.17733	-0.75006	-0.94893	0.00608	0.96602	0.05433
SO4	0.03	-0.02	0.05	0.29	1.03161	0.00456	1.17802	-0.78917	-1.09855	0.00932	0.81295	0.05769
NNO3	-0.03	0.02	-0.00	0.24	0.16694	-0.00128	0.12348	0.26137	-3.22299	-0.00014	-1.31251	0.04826
NNH4	0.04	-0.08	0.11	0.31	0.08254	0.00110	0.14447	-0.63903	-4.00939	0.02424	-2.09297	0.07236
CL	-0.05	0.15	0.08	0.36	0.10734	-0.00148	-0.00013	1.26320	-3.44275	0.01183	-1.53401	0.06024
CA	-0.12	0.14	-0.06	0.14	0.10280	-0.00285	-0.01048	0.85583	-3.59524	-0.01428	-1.70514	0.03491
MG	-0.10	0.16	-0.12	0.46	0.01626	-0.00039	-0.00191	0.16200	-4.23043	-0.00934	-2.34065	0.03986
NA	-0.03	0.08	-0.07	0.16	0.04090	-0.00073	-0.00400	0.48199	-3.83289	-0.01396	-1.93367	0.03482
K	0.04	-0.02	0.03	0.36	0.00631	0.00019	0.01166	-0.02138	-4.36124	0.00420	-2.45336	0.05260
F	-0.03	0.01	-0.08	0.15	0.00869	-0.00007	0.00686	0.00473	-4.15979	-0.01737	-2.28211	0.03270
FE	-0.19	0.25	-0.22	-0.00	0.10393	-0.00293	-0.02025	1.00937	-3.87898	-0.04900	-1.97727	-0.00028
CU	-0.21	0.21	-0.19	0.05	0.02441	-0.00057	0.00268	0.15692	-5.10793	-0.03851	-3.20432	0.01011
NI	-0.23	0.24	-0.36	-0.01	0.00962	-0.00024	0.00038	0.06800	-5.43397	-0.05112	-3.54327	-0.00184
PB	-0.12	0.15	-0.04	0.22	0.01020	-0.00015	0.00395	0.05059	-5.70818	-0.00776	-3.80584	0.04090
ZN	-0.08	0.09	-0.08	0.16	0.01353	-0.00025	0.00343	0.07649	-5.56836	-0.01690	-3.65729	0.03142
AL	-0.23	0.30	-0.27	0.02	0.07619	-0.00230	-0.02133	0.79549	-3.82250	-0.04591	-1.93324	0.00347
CR	-0.16	0.18	-0.02	0.35	0.00045	-0.00001	0.00005	0.00291	-8.08459	-0.00300	-6.17218	0.04530
CD	-0.03	0.09	0.02	0.15	0.00022	-0.00000	0.00012	0.00118	-10.0258	0.00921	-8.11513	0.05755

TABLE 20: DEPENDENCE OF FALCONBRIDGE ADDITIONAL CONCENTRATION ON DISTANCE FROM SOURCE USING GROUPED DATA POINTS

CONC = A1 + B1 * R (1)
CONC = A2 + B2 / R (2)
LN(CONC) = A3 + B3 * R (3)
LN(R * CONC) = A4 + B4 * R (4)

PARAMETER	CORRELATION COEFFICIENT COR1	COR2	COR3	COR4	REGRESSION COEFFICIENT A1	B1	A2	B2	A3	B3	A4	B4
HF	0.28	-0.37	0.29	0.90	0.01698	0.00011	0.02289	-0.05628	-4.09878	0.00543	-2.08962	0.04696
ACID	0.21	-0.01	0.14	0.92	1.04152	0.00506	1.19097	-0.12219	0.04567	0.00289	2.05484	0.04441
SO4	-0.09	0.03	-0.21	0.87	1.14407	-0.00159	1.08970	0.18630	0.16418	-0.00337	2.17336	0.03816
NNO3	-0.70	0.61	-0.71	0.89	0.17111	-0.00135	0.10912	0.46707	-1.74069	-0.01060	0.26848	0.03093
NNH4	-0.05	-0.17	-0.23	0.64	0.09879	-0.00014	0.10436	-0.19010	-2.23671	-0.00790	-0.22754	0.03363
CL	0.29	0.05	-0.04	0.78	0.02867	0.00191	0.07563	0.14063	-3.55519	-0.00893	-0.94315	0.05603
CA	-0.81	0.84	-0.74	0.13	0.09590	-0.00229	-0.01673	0.94540	-0.08342	-0.16277	-0.48849	0.00460
MG	-0.49	0.69	-0.30	0.83	0.01357	-0.00025	-0.00048	0.13848	-5.03643	-0.06899	-2.42516	0.03255
NA	0.28	-0.03	0.01	0.82	-0.00937	0.00121	0.02741	-0.04813	-4.68365	0.00159	-2.12658	0.06441
K	0.75	-0.44	0.66	0.94	0.00252	0.00033	0.01557	-0.07470	-5.32102	0.02593	-3.31186	0.06746
F	-0.43	0.19	-0.61	0.13	0.01137	-0.00015	0.00577	0.02673	-4.25060	-0.03465	-2.24142	0.00688
FE	-0.72	0.90	-0.45	-0.26	0.07456	-0.00156	-0.00862	0.77551	-2.36670	-0.12639	-0.48254	-0.03442
CU	-0.82	0.91	-0.78	-0.25	0.02076	-0.00041	-0.00010	0.18121	-3.59242	-0.05227	-1.58326	-0.01074
NI	-0.84	0.86	-0.86	-0.52	0.00854	-0.00018	-0.00038	0.07421	-2.39473	-0.17741	-2.18807	-0.02624
PB	-0.56	0.63	-0.48	0.80	0.00988	-0.00010	0.00455	0.04672	-4.67242	-0.01331	-2.66327	0.02822
ZN	0.14	0.26	-0.12	0.43	0.00696	0.00008	0.00618	0.06159	-5.27899	-0.02241	-2.90456	0.03331
AL	-0.70	0.92	-0.75	-0.28	0.05704	-0.00133	-0.01538	0.68845	-3.23171	-0.07181	-0.78460	-0.01326
CR	-0.76	0.91	-0.53	0.01	0.00037	-0.00001	0.00001	0.00327	-7.94462	-0.04106	-5.93547	0.00047
CD	0.41	-0.01	0.29	0.93	0.00013	0.00000	0.00023	-0.00003	-8.76077	0.00900	-6.75159	0.05053

Table 21: Summary of Particulate-to-SO_2 (M/SO_2) Ratios

Parameter (M)	INCO 381 m Chimney	N	INCO IORP Stack°	Falconbridge Stack	N	Low Level++
Fe	$(3.55 \pm 2.41) \times 10^{-4}$	23	4.14×10^{-3}	$(3.44 \pm 2.67) \times 10^{-4}$	23	-
Cu	$(1.81 \pm 1.64) \times 10^{-4}$	30	9.85×10^{-4}	$(7.86 \pm 6.39) \times 10^{-5}$	28	-
Ni	$(1.04 \pm .66) \times 10^{-4}$	28	2.74×10^{-3}	$(4.82 \pm 4.82) \times 10^{-5}$	28	-
Pb	$(2.06 \pm .63) \times 10^{-4}$	22	2.04×10^{-4}	$(1.26 \pm .55) \times 10^{-4}$	28	-
Zn	$(4.48 \pm 4.40) \times 10^{-5}$	26	1.47×10^{-4} +	$(1.96 \pm .42) \times 10^{-5}$	2	-
Al	$(1.74 \pm 1.26) \times 10^{-4}$	5	**	$(1.10 \pm .09) \times 10^{-4}$	3	-
Cr	$(4.6 \pm 4.5) \times 10^{-5}$	6	1.00×10^{-4} +	3.59×10^{-6}	1	-
Cd	$(1.63 \pm 1.87) \times 10^{-5}$	17	1.30×10^{-5} +	$(4.08 \pm 5.06) \times 10^{-5}$	19	-
SO_4	$(1.83 \pm .94) \times 10^{-2}$	43	4.85×10^{-2}	$(1.62 \pm .48) \times 10^{-2}$	28	-
H^*	$(3.81 \pm 1.96) \times 10^{-4}$	43	1.01×10^{-3}	$(3.37 \pm 1.0) \times 10^{-4}$	28	-

°Single measurement

+Based on incomplete cycle data, i.e. individual or combination of background flue, blow, charge and reduction phases.

*Based on assumption that all SO_4 are associated with H_2SO_4 which gives rise to H^+

**Assumed to be the same as that of the INCO 381 m chimney

++Assumed to be the same as that of the smelter stack

TABLE 22: WET DEPOSITION OF INCO EMISSIONS (r=40Km)

Parameter	NN*	N*	Emissions (Kg)	Wet Deposition (Kg)	% Scavenged	Background Deposition (Kg)	% Total Deposition
H_f	113	403	449	142	31.6	2,254	5.9
SO_4	115	405	21,549	10,277	47.7	111,579	8.4
S	115	405	519,683	3,426	0.66	37,193	8.4
Fe	113	396	714	484	67.8	1,938	20.0
Cu	113	396	260	272	104.6	121	69.2
Ni	113	401	351	126	35.9	61	67.4
Pb	112	394	211	70	33.2	431	14.0
Zn	112	393	55	51	92.7	380	11.8
Al	112	393	178	142.2	79.9	1,642	8.0
Cr	110	382	52	1.2	2.3	14.2	7.8
Cd	111	402	16.4	3.7	22.6	9.7	27.6

* NN = Number of sampling days; N = number of samples

TABLE 23: WET DEPOSITION OF FALCONBRIDGE EMISSIONS (r=40km)

Parameter	NN⁺	N⁺	Emissions (Kg)	Wet Deposition (Kg)	% Scavenged	Background Deposition (Kg)	% Total Deposition*
H_f	85	214	48.3	169	350	2,381	6.6
SO_4	86	217	2,318	9,252	399	109,045	7.8
S	86	217	72,323	3,084	4.3	36,348	7.8
Fe	82	204	49.2	254	516	1,902	11.8
Cu	82	204	11.3	75	664	133	36.1
Ni	81	202	6.9	28	406	65	30.1
Pb	83	205	18.0	58	322	454	11.3
Zn	82	203	2.8	78	2,786	428	15.4
Al	79	199	15.7	160	1,019	1,343	10.6
Cr	82	203	0.51	1.4	275	14.3	8.9
Cd	82	203	5.8	1.9	33	16.1	10.6

* Assuming 100% of emissions scavenged except in the cases of S and Cd for estimation of the maximum depositon contribution

TABLE 24: SEASONAL VARIATION OF SCAVENGING PROPERTIES OF INCO EMISSIONS (r=40km)

Parameter	Summer Emissions (Kg)	Summer Wet Deposition (Kg)	Summer % Scavenged	Winter Emissions (Kg)	Winter Wet Deposition (Kg)	Winter % Scavenged
H_f	323	181	56.0	521	83	15.9
SO_4	15,522	11,796	77.5	25,050	7,850	31.3
S	369,774	3,932	1.1	607,850	2,617	0.43
Fe	531	274	51.6	815	728	89.3
Cu	190	161	84.7	300	300	128
Ni	266	75	28.2	396	183	46.2
Pb	150	54	36.0	247	86	34.8
Zn	40	51	127.5	64	50	78.1
Al	117	22	18.8	209	264	126
Cr	37	1.2	3.2	61	0.7	1.1
Cd	12.7	2.6	20.5	19	5.3	27.9

TABLE 25: SEASONAL VARIATION OF INCO WET DEPOSITION RELATIVE TO THE TOTAL DEPOSITION* (r=40Km)

	Summer			Winter		
Parameter	INCO Deposition (Kg)	Background Deposition (Kg)	%**	INCO Deposition (Kg)	Background Depsosition (Kg)	%
H_f	181	2,559	6.6	83	1,952	4.1
SO_4	11,796	156,035	7.0	7,850	74,181	9.6
S	3,932	52,012	7.0	2,617	24,727	9.6
Fe	274	2,133	11.4	728	1,763	29.2
Cu	161	119	57.5	385	120	76.2
Ni	75	54	58.1	183	64	74.1
Pb	54	430	11.2	86	422	16.9
Zn	51	402	11.3	50	356	12.3
Al	22	1365	1.6	264	1,829	12.6
Cr	1.2	17.6	6.4	0.7	11	6.0
Cd	2.6	7.7	25.2	5.3	11	32.5

* Kg during an average precipitation period

** INCO /(INCO + Background)

TABLE 26: ESTIMATED SCAVENGING COEFFICIENTS (S^{-1}) IN INCO PLUME

Parameter	All Season $\times 10^4$	Summer (S) $\times 10^4$	Winter (W) $\times 10^4$	S/W
H_f	0.47	1.0	0.22	4.5
SO_4	0.81	1.9	0.47	4.0
S	$.83 \times 10^{-2}$	1.4×10^{-2}	0.54×10^{-2}	2.6
Fe	1.4	0.91	2.8	0.33
Cu	-	2.3	-	-
Ni	0.56	0.41	0.77	0.53
Pb	0.50	0.56	0.53	1.06
Zn	-	-	1.9	-
Al	2.0	0.26	-	-
Cr	2.9×10^{-2}	4.1×10^{-2}	1.4×10^{-2}	2.9
Cd	0.32	0.36	0.41	0.88

* Using an average wind speed of 5 ms^{-1}; t = 8,000s, r = 40 Km

TABLE A1

Sample Handling Criteria for Limited Volume Precipitation Samples

Volume Collected (ml)	Handling Method
Less than 50	- pH measured at the field office - no sample submitted for chemical analysis
50 to 150	- no field pH measured - no metals analyses submitted - total volume submitted for laboratory analysis of major ions and pH
150 to 250	- no field pH measured - 25 ml placed in metals bottle - balance of volume submitted to laboratory for major ions, pH and acidity analysis.
250 to 500	- field pH measured - 25 ml transferred to metals bottle - balance submitted to laboratory for major ions, pH, acidity and conductivity analysis.
greater than 500	- field pH measured - metals bottle filled with 50 ml - balance submitted for major ions, pH, acidity and conductivity analysis.

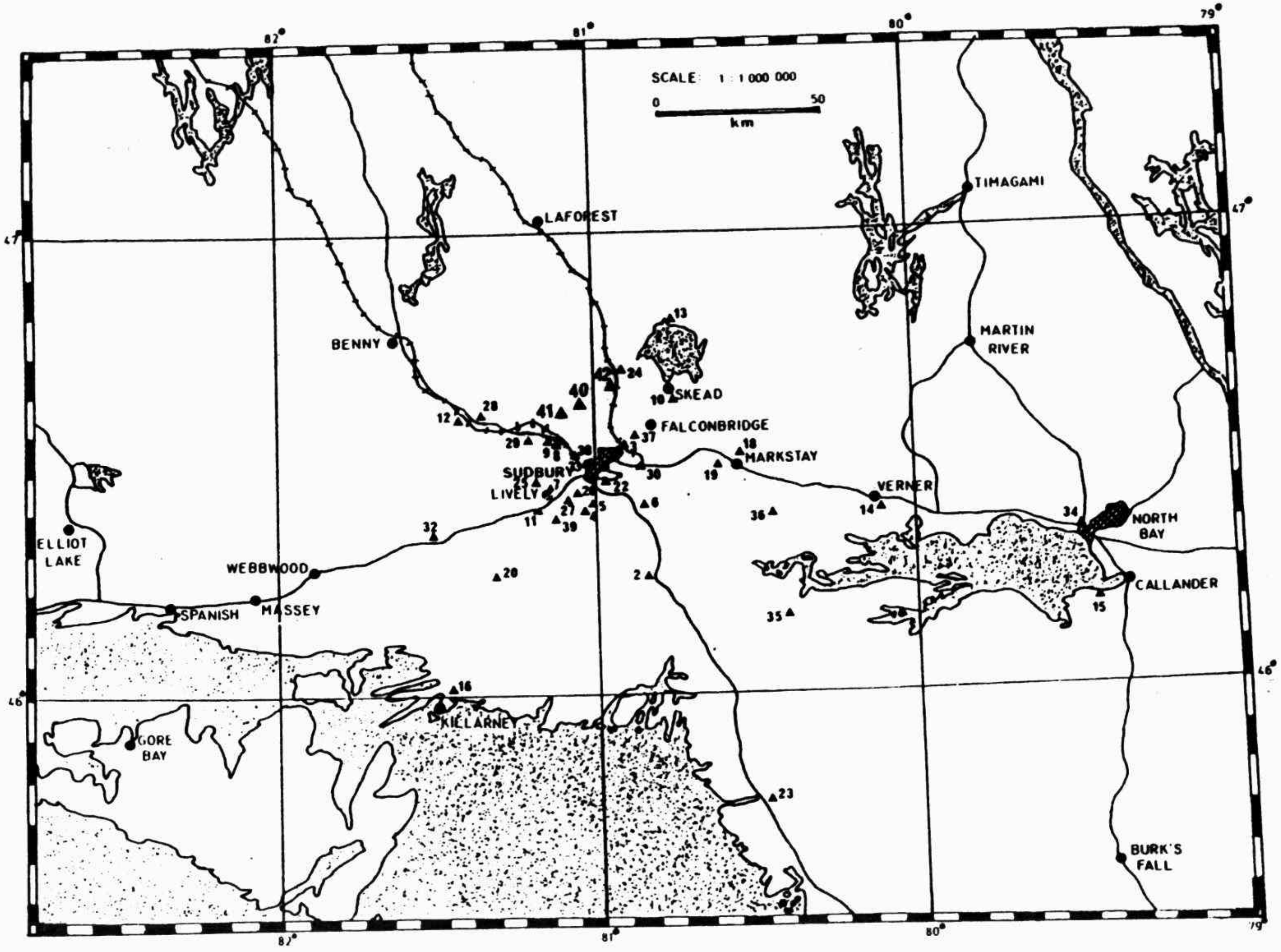

Fig. 1. SES event sampling network.

APPENDIX 1

SES EVENT NETWORK OPERATIONS

A1.1 Network Design and Operations

The network consisted of approximately 20 samplers located within a 50 Km radius of Sudbury. The distribution of sites was roughly equivalent in all directions but the total number and location of sites varied considerably. In general, 20 to 25 sampling were operated in the summer and 10 to 15 in the winter. The configuration of the network at any time reflected the availability of suitable sites and sampling operators. Because of these unavoidable constraints, this network can be viewed as a network designed primarily for the assessment of the INCO source.

The locations of the sampling sites used (except for the distant locations - Charlton Station, Ramsay, Thessalon and Blind River) in the Event Network are shown in Figure 1 and the co-ordinates of the sites are given in Table 1. The operation period of each site is summarized in Table 2.

Prior to the installation of a precipitation sampler, each sampling site was carefully inspected to ensure that it satisfied a specific set of site selection criteria. These criteria were designed to eliminate sources of sample contamination and interference (e.g. roads, trees) and are summarized elsewhere (1). Although most sites fulfilled the criteria, some compromises were necessary at some of the sites.

The sampling was carried out on a 24 hour basis using large diameter open collectors. As such, it was not true wet only event sampling. The assumption was made that, with stringent siting criteria, dry deposition did not significantly affect the collected precipitation over the 24 hour period.

Most samplers were located on privately owned property and were operated by individuals contracted to carry out the sampling. Sudbury Environmental Study field staff oversaw the training and organization of the network as well as the collection and field analysis of the samples.

A1.2 Instrumentation

The precipitation collector used in this network consisted of a large diameter polyethylene bucket with a polyethylene bag insert. Two models of the sampler were used and the transition took place in May, 1979. The former (called the 1978 sampler) consisted of a black high density polyethylene bucket, 42 cm OD by 47 cm high, and a standard, food-grade, linear polyethylene bag insert. The latter sampler (called the 1979 sampler) consisted of a 44.5 cm OD 56.6 cm high, green polyethylene bucket with a custom-made polyethylene bag insert. This bag had an extra seal running from the mid-point of one side diagonally towards the bottom of the other side. At the end of the seal was an opening which allowed precipitation to funnel into the compartment below the seal. This design was implemented to reduce the effect of evaporation on the collected sample. It was used in the summer and autumn periods only while the standard bag without the seal was used in the winter and spring.

Extensive laboratory testing was carried out on the bags prior to their use. It was confirmed that no detectable adsorption or desorption of ions or metals took place on the bag walls over a 24 hour period (19).

The effective collection area of both the 1978 and 1979 samplers was 1410 cm^2. This was somewhat smaller than the actual size of the bucket

openings and was due to folding of the bag at the upper edges of the bucket.

The precision of both types of collectors for sampled volume was measured in a special study carried out between November 1979 and May 1980. In this study, two 1978 collectors and three 1979 collectors were operated concurrently at the Kelly Lake 1 site. It was found that the average coefficient of variation (C of V = standard deviation/mean) for all 80 events was 8.7% for the 1978 collector and 10.6% for the 1979 collector. In general, both samplers were less precise for snow collection than for rain collection.

It was assumed that both samplers were at least as efficient for the collection of rain as the standard Canadian rain gauge. However, the collection efficiency of these samplers for snow was unknown and thought to be highly variable. Another special study was carried out from November 1979 to March 1980 at the Kelly Lake 1 site to test this. The results showed that over 27 snow events, the average collection efficiency of the 1979 sampler when compared to the Canadian standard nipher snow gauge was $84.4 \pm 48.3\%$. The magnitude of the standard deviation indicates that the collection efficiencies were quite variable from event to event and this is confirmed by the range of efficiencies -from 8% at minimum to 230% at maximum. Variations in wind speed and type of snow were the principal factors in the efficiency variations.

A1.3. Sample Collection and Handling Procedures

Sample collection took place typically from 0800 hours to 0800 hours local

time every day of the week ($\pm$ 2 hours). The field protocol required that operators visit the sites even if precipitation did not occur in the previous 24 hours. In such cases, the exposed polyethylene bag was discarded and a clean one was inserted in the collector. Disposable plastic gloves were used whenever bags were handled.

In cases when precipitation was collected, the bag was removed, a bottom corner was cut and the sample was transferred to two 450 ml. polystyrene bottles (given enough volume) and one 60 ml polyethylene bottle. All bottles were then stored in a refrigerator on-site and a sample submission form was completed. Included on the form was information on the date and time of collection as well as the quality of the sample. For snow events, the samples were allowed to melt at room temperature before being transferred.

In 1979 and 1980, five sampling sites were operated by SES technical staff. For these samplers, the sample transfer took place at the SES field laboratory on the day the sample was collected. For the other samplers, the stored samples were collected at least once per week and transported to the SES field laboratory. At this time, a 50 ml aliquot was taken from the polystyrene bottles and the pH was measured. This pH was designated as the "field pH" throughout the program to distinguish it from the laboratory pH taken later in Toronto. Also at this time, the 60 ml bottle was spiked with 0.5 ml of 5% nitric acid for later trace metal analysis. All bottles were then stored in a refrigerator before being shipped by courier to the Laboratory Services Branch in Toronto.

In the event that the amount of precipitation collected was less than 0.05 litre, specific sample handling criteria were followed to obtain the most useful information from the limited sample. These criteria are summarized in Table A1.

A1.4 Chemical Analysis

Chemical analysis of the samples was carried out by the Laboratory Services Branch of the Ontario Ministry of the Environment in Toronto. Samples stored in the polystyrene bottles were analyzed for: pH, acidity, SO_4, NO_3, NH_4, Ca, Na, K, Mg, Cl, F; samples stored in the acidified polyethylene bottles were analysed for Fe, Ni, Cu, Pb, Zn, Al, Cr and Cd. The samples were not filtered prior to analysis. Conductivity was also measured to check the ionic balance.

The analysis methods used by the Laboratory are summarized in Table 3 together with their corresponding detection limits. Concentrations of NO_3 and NH_4 were expressed as N-NO_3 and N-NH_4. In the beginning of the sampling program, samples were also analyzed for Br and Si; however these were later deleted from the parameter list because they were consistently below detection limits. Note also that in many of the samples identified in the present report as "background", Cu and Ni occurred at concentrations below the detection limits of the analysis method used. In these cases, the data in Section 1 of the Supplementary Volume are given as being at the detection limit (0.001 mg per liter).

In 1980, the method of analysis for all trace metals except Fe and Al

changed from atomic absorption spectroscopy (AA) to inductively coupled plasma spectroscopy (ICP). However, those samples with metal concentrations near the detection limits of ICP were re-analysed by flameless AA.

Prior to the adoption of ICP as the metals analysis method, a comprehensive study was carried out at the Laboratory Services Branch to ensure that ICP and AA produced compatible results. The results of the study were favourable (except for Fe and Al) and are described elsewhere (20).

It is useful to point out here that pH is a measure of the free acidic component of precipitation due to strong mineral acids (mainly sulfuric and nitric). It is equal to the negative logarithm of the free hydrogen ion concentration (in moles per litre). Total acidity, on the other hand, which is related to the total hydrogen ion concentration, is a measure of the capacity of the precipitation sample to neutralize a base, and is made up of the contribution due to strong and weak acids (carbonic acid, organic acids, hydrolyzable metallic salts, etc).

Free hydrogen ion H_f and total hydrogen ion H_t concentrations (in mg per liter) can be calculated according to the following expressions:

$H_f^+ = 10^{-pH} \times 10^3$

and

H_t^+ = Acidity (in mg Ca CO_3 per liter) /50

A1.5 Network Performance.

Samplers were operated at a total of thirty-nine stations throughout the course of the program. Of these, only five stations were in operation throughout the entire study period. These were Burwash, Wanup, Verner, Lake Panache and Laurentian University. The operation of the remaining stations depended on the time of year, the location and the availability of on-site personnel.

Table 2 summarizes the operating period and the number of samples from each station for which volume and pH were measured and included in the final SES event precipitation database. It should be pointed out that this summary does not show the total number of samples taken at each site since some samples were rejected from the database. The criteria for the rejection of data are given elsewhere (3). It should also be pointed out that the number of analyses of major ions and metals was smaller than those shown for pH in Table 2 because of limited sample volumes.

It is obvious from Table 2 that some stations operated more consistently than others and that the smoothest operation occurred from mid-July, 1979 to the end of the program. This should be borne in mind, since all samplers did not provide data for all events.